BELOVED SCIENTIST

Professor Elihu Thomson

BELOVED SCIENTIST

ELIHU THOMSON

A Guiding Spirit of the Electrical Age

BY

DAVID O. WOODBURY

WITH A FOREWORD BY

OWEN D. YOUNG

New York WHITTLESEY HOUSE *London*

McGRAW-HILL BOOK COMPANY, INC.

BELOVED SCIENTIST

PUBLISHED BY WHITTLESEY HOUSE

A division of the McGraw-Hill Book Company, Inc.

Printed in the United States of America by The Maple Press Co., York, Pa.

This Book Is Dedicated to the Men and Women
Everywhere Who Loved
Elihu Thomson
and Understood the Importance
of His Great Contributions to Science

Elihu Thomson would have been great in any field to which he chose to direct his talents. He was in fact great in many fields.

It was the good fortune of the electrical industry that his early training and youthful experimentation accentuated his interest in the electrical field. It was fortunate, too, that circumstances, largely of his creation and not the result of accident, encouraged Elihu Thomson's pursuit of the unknown in this ever-widening field. He found more problems to be solved at eighty than he dreamed of at twenty. His confidence had increased too—a confidence that man could always reduce the unknown to the known.

In *Beloved Scientist* Mr. Woodbury has done a superb work in formulating and stating the main facts of Professor Thomson's life.

OWEN D. YOUNG.

NEW YORK,
November 22, 1943.

Illustrations

Author's Note

There is no record that Elihu Thomson ever had an enemy in the world. Few struggled against him, either personally or professionally. Nature herself was largely docile when he sought her help in making an invention or discovery. His friends adored him; men of every nationality were in remarkable agreement in acclaiming his great qualities. Thousands who knew him slightly or not at all listened to him with an affection and respect reserved for history's greatest humanitarians. He was a man without blemish, against whom none wished to voice criticism or calumny.

This fact has made the writing of Professor Thomson's biography both delightful and uniquely difficult. For dramatic interest in a personal narrative is commonly attained by recounting the subject's struggles with his rivals and his enemies. If the story is to be human, so the rules of storytelling say, red blood must flow. It must gush forth from a wound, so that the stanching of it may create suspense and excitement. There must be suffering and striving, anguish and defeat.

As a biographical subject the Professor has broken these rules just as completely as he did those of human frailty. He bled little, and his hurts were the universal ones of personal bereavement that are not news. His life moved smoothly through its eighty-three years upon a course appointed by the gods themselves. He struggled with no rivals, created no hatred anywhere. He bequeathed to his biographer a beautiful problem in dramatizing the conventionally undramatic.

I have approached this problem from the only direction that could promise a solution, that is, by asking the Professor to write his biography for himself. My argument has been plainly this: since Elihu Thomson was a man so extraordinarily loved and respected by the whole world of science—and so reverently remembered by it now—those same emotions can be called forth again, simply by describing him as he was, by causing him to live in every

page of the book. That is all I have tried to do—to make him live again.

There was little struggle in his life, perhaps, but there was drama aplenty. It was the drama of motion. Just as there is excitement in the headlong rush of a comet through the heavens, so is there innate fascination in the man who is forever going ahead, opening new depths of the wilderness to human understanding and use. There is appeal in the constant growth of human aspirations, and in the man who dreams of them and then causes that dream to become reality itself.

Elihu Thomson made a journey into the unknown and it was in a sense a journey alone, since in two respects he was set apart from nearly everyone he knew. In his great and instinctive knowledge of nature and her processes, he explored a world of his own, while others were content to wait till he brought back to them the practical results of his researches. In his complete unselfishness and personal humility he lived in a world of his own, unwilling to enter into those jealousies and competitions by which most men seem to measure achievement.

Beloved Scientist is the unadorned story of the man who made this solitary journey and brought back a new world for others to enjoy.

* * * * *

I should not have got far with this considerable biographical task had I not had the constant support of those who worked with Professor Thomson or were related to him. First, there was Albert L. Rohrer, whose devotion to the Professor's memory has been second only to his devotion to the man himself. Then, Professor D. C. Jackson, whose guidance in managing the complicated engineering material has been of primary importance to me. Then his widow, whose great energy and optimism have helped the project through. Then Dr. W. R. Whitney, whose understanding of his beloved mentor and colleague brought the Professor to life again before my eyes. Then his three sons, his brother, and his grandson, as well as other members of the family, all of whom worked generously to make the background portrait complete.

Beyond these, too, there are many others, not one of whom but has given generously of his time and thought in the midst of heavy

war duties: among them Thomson's lifelong secretary, J. A. McManus; his associate of mountain-climbing days, J. R. Lovejoy; his dear friend, Edward Mallinckrodt; his faithful one-time assistant, Hermann Lemp. And I should be ungrateful indeed if I did not mention also Mrs. Gertrude Hess, librarian of the American Philosophical Society, by whose devoted efforts the vast Elihu Thomson collection was catalogued and organized, so that all necessary documents were readily available to me.

DAVID O. WOODBURY.

BRONXVILLE, N.Y.
December 10, 1943.

BELOVED SCIENTIST

Chapter 1

1

Elihu Thomson was born on the twenty-ninth of March, 1853, in Manchester, England. He could not have chosen a better moment to venture forth on a career of invention and discovery, for his maturity was to coincide with the greatest scientific advance in history.

For centuries the natural philosophers had stumbled painfully up the mountainous slopes toward new knowledge, losing their way, stopping to argue the path, struggling on again. Bacon, Newton, Franklin, Cavendish, Davy, Ampère, Faraday, Henry—one by one they had pushed a portion of the way until now, in mid-nineteenth century, science was at last approaching a critical point in the climb. Ahead lay the precipitous canyons of a Pass which would lead quickly to a broad plateau of untold intellectual and material wealth.

In twenty-five swift years at the end of the century, that Pass would be won. There would be years of violent transition from an old way of living to a new—years when a slow-moving, contemplative past would suddenly be wrenched aside to make room for a noisy world of mighty forces harnessed to machines that would serve men or destroy them.

In the little period of the crossing would come nearly all the material possessions that we live by, and many of the philosophical ones as well: electric light, telephone, dynamo and steam turbine, wireless, X-rays, trolley car, automobile, and airplane, the beginnings of applied chemistry and astronomy, the birth of industrial research, and the first broad understanding of a physical universe in which the infinitesimal electron and the vast nebula of stars could exist side by side in obedience to one divine law.

This tremendous period of advance was to coincide exactly with Elihu Thomson's years of greatest productivity. No man who would accompany him through the Pass would be more sturdy, more resourceful, or surer of foot than he.

There had been mechanical talent among Thomson's forebears for generations. Elihu's father Daniel was the youngest of twelve born to the Scotchman James Thomson. Grandfather James had been a mechanic of Glasgow in the days when the great James Watt was busy revolutionizing all Britain with his reciprocating steam engine. Nothing is recorded of the forebears of James, but it is fair to assume that the mechanical talent was an old one in the family, since nothing descends more surely from father to son than the "feel" for machines.

Daniel Thomson took after his father and became a mill mechanic and engineer—a new term that described the use of the head as well as the hands in the manipulation of machinery. He moved south presently, to settle in the English midlands and become moderately successful in his profession.

James Tenant, a maternal great-grandfather, had been a prosperous Huguenot shipowner who migrated to Scotland and raised four children there. His daughter Nancy had married Joseph Rhodes, a Scotch bootmaker whose manual skill became a byword throughout the north country. The Rhodeses raised a family of ten, one of whom, Mary Ann, married Daniel Thomson and so joined the artisan's fine hand to the mechanical mind.

The Scotch background of both families explains the spelling "Thomson," without the "p." But only chance accounts for the curious fact that the name, by either spelling, has outdistanced all others in its total of scientific fame. There are at least five unrelated owners of it who will be remembered always: Count Rumford, born Benjamin Thomson in Woburn, Mass.; Lord Kelvin, originally William Thomson of Scotch descent; Sir Joseph J. Thomson; Silvanus P., of the English spelling; and Elihu himself. If there was relationship among them all they did not know it.

Elihu was the second of ten children to be born to Daniel and Mary Ann Thomson. Manchester was a great factory town, and Elihu's father liked to take him to the doors of the plants, to look in at the large steam engines and the long lines of power looms with their forest of flapping belts. Elihu loved these visits and always begged for more. The clatter and motion excited in him a curiosity which his brothers lacked. He was a great child for observing everything that went on around him, whether it was in the

factories or in the fields near his home. At four he already showed that fundamental quality of all true scientists: the talent for inquiry into the causes of action.

The mathematical genius, James Clerk Maxwell, growing up in Edinburgh a few years before, had shown that same questioning spirit at the age of three. "What's the go of that, now?" he would chirp with his thick little Scotch burr, whenever some new device met his gaze. And if not painstakingly answered, he would demand again immediately, "No, no! what's the particular go of that? The *particular* go, I say!"

Young Michael Pupin, too, a shepherd boy on the Serbian plains at this same period, was questioning the stars and the wind and the nature of the transmission of sound through the earth. Every scientific mind develops first the faculty of study and deduction, the ability to reason from cause to effect, even in earliest childhood.

In the bustle of a household that already contained four children, Elihu's habit of observation early set him apart from the others. When six-year-old Daniel was being taught his letters, Mrs. Thomson turned to her younger son and said, "Soon it will be your turn to learn the alphabet."

"I know it now," said Elihu quietly, "Forwards—and backwards." And much to Daniel's discomfort, he recited the letters both ways without a hitch. He had taught himself the whole thing while silently looking on at his brother's lessons. Delightedly, his father took him on one knee that evening and, opening the family Bible, began teaching him to read. Elihu at four had become the bright boy of the family.

When the money panic of 1857 swept over England, the factories were hard hit and Daniel Thomson lost his job. He was soon reduced to day labor and became so alarmed at his prospects that he determined to move his whole family to America. After a bleak Christmas he sold his house and furniture and bought passage on the *Tuscarora*, a tiny sailing vessel leaving Liverpool for New York in February.

The long voyage across the Atlantic was Elihu's first adventure of any kind and he was busy every mile of it, watching the crew manage the sails and learning to walk the sloping decks on sturdy sea legs. Mrs. Thomson and the baby were confined to their berth

in the saloon, with the other children clinging close by. Even Daniel kept below most of the time, wretchedly seasick. But Elihu sallied forth on his own. He made such an impression on the officers by his intelligent interest in the ship and the sea that the captain asked Daniel Thomson to let him apprentice the child as cabin boy and bring him up to be a shipmaster. To Elihu's sorrow his father refused.

The young observer was delighted when a storm overtook them in mid-ocean, and soon he was the only passenger to keep his feet. It came in the night, heralded by a sudden deluge of water bursting down the companionway and flooding the saloon in which the cabin passengers all slept together. Groggily, Daniel Thomson found a rope and lashed his three sons into their upper bunk. Then he crawled back in below to comfort his wife as well as he could.

Professor Thomson remembered the occasion years after. "We had been struck by a heavy gale which rolled the ship so violently that trunks and boxes and barrels of food got loose and lunged about. All night long I could hear the sailors running around the deck over my head trying to capture them and tie them down. I remember especially the terrific roar of the wind in the rigging and the shudder of the vessel as she hit one impenetrable wall of water after another. There was evident danger in it, for many of the passengers fell to their knees and prayed for deliverance, fearing that they were about to be drowned."

That was sea travel in 1858. But the *Tuscarora* survived and in March brought them safely into New York. Thomson did not linger there but moved his family on to Philadelphia at once, on the promise that mechanical work could be found there in abundance.

2

Impressions in the new land crowded in so rapidly that Elihu soon forgot the loss of his seafaring career. The first was of a small damp house in Philadelphia's crowded Richmond section; the next a confusing turmoil of locomotives charging through the streets with long lines of freight cars screeching around the curves behind them; and then—a suddenly opening world of surprises, bringing such adventures as he had never dreamed of in England.

The last was his mother's doing. A woman of less spirit might

have sunk into the hopeless routine of feeding her family and keeping it clean. But not Mary Ann Thomson. She knew that America was the land of opportunity; she was determined to find it and bring it to her children.

Just around the corner was a main thoroughfare called American Street and at the end of it a huge railroad roundhouse which poured smoke and steam into the air day and night. Elihu quickly found an incline of planks behind this where sweating horses tugged an endless stream of coal wagons upward to be dumped into the bins for the locomotives below. Without hesitation he followed the wagons to the top and found a place where he could sit, legs dangling, to survey the vast empire of the railroad. That first night he described to his mother what he had seen and she listened with interest and excitement. Next day, with her full approval, he went again, and for many days thereafter, till the last mystery of the roundhouse had been solved.

As spring advanced he discovered down by the Delaware a wide stretch of meadowland and thicket and, farther on, real woods. It was even more absorbing here than at the railroad yards, for the countless kinds of insects all seemed to know exactly what they were about.

Long days he spent that summer, standing motionless among the bushes, learning how the small creatures ran their world. He saw that they never quarreled, never missed a landing on a blade of grass, never hesitated or lost a moment in indecision. Again he brought his observations to his mother and again she encouraged him to describe all he had seen. Not once did she talk of danger or belittle the importance of what he told. She had the rare faculty of placing herself on her children's level, living their adventures with them, skillfully training them to understand and to explain all that they observed.

Elihu soon developed the gift himself and was immeasurably the broader for it, since it gave him the habit of simplifying his own scientific thought.

One evening in the early fall Mrs. Thomson took Elihu and his brother Daniel to the head of the street, where a broad view of the western heavens opened above them. There in the chilly night sky the great tawny arch of Donati's comet soared over the countryside.

"Look closely," the mother urged, "for you may never see one like it again." Elihu looked so closely, then and on many another night, that after seventy years he could still "see that great sweep of light like a huge brush of yellow, arched with the concave side downward across the darkened city."

Donati's comet was one of the largest ever to visit the solar system and was visible for seven months. Thousands believed that it came as a warning of impending doom and were certain of it when Swift's great comet appeared in 1861 against the red skies of the opening Civil War. But the superstition did not touch Elihu. It was Donati's that he remembered and loved as a magnificent display of nature, because of his mother's childlike delight as she stood at his side.

After several months Daniel Thomson got work as an installation engineer for a sugar machinery company and moved his family to a southern section of the city called "The Neck." On moving day the father took two of the boys on the dray with the household goods, but Mrs. Thomson insisted on the luxury of a horse-car for herself and the baby. After much pleading Elihu was allowed to join in this adventure too.

It was late November, and the interior of the horse-car, when it finally arrived, was stale and cold. It was a tiny affair with its wheels so close together that it bucked incessantly like a vessel at sea. Its hard benches seated only six people on each side; there was no heat at all. The floor was buried in coarse straw, into which the male passengers spat tobacco continually. As the car clattered over the uneven track it developed a peculiar corkscrew roll which threw the people about indiscriminately, while the strong smell of horse and work clothing that had been with it for thirty years thickened the air. Mrs. Thomson was the only woman present. She huddled as best she could into a corner, gathering boy and baby to her breast to conserve the family warmth.

Elihu sat round-eyed and enthralled, listening to the driver barking at the horses and watching him grind the big iron wheel that set the brakes. Twenty-five years after he would look back on that dismal ride with a smile, as he designed one of the first electric motors which was to make the horse-car obsolete at last.

"The Neck" was a rough and ready American neighborhood where factories and warehouses crowded long lines of little brick

dwellings into the triangle between the Delaware and Schuylkill rivers. It was better than the railroad yards of Richmond, but still a long way from the genteel environment the family had been used to in Manchester. Thomson's work took him to Cuba for several months every year, and his wife and the children were forced to become entirely self-reliant in an unfamiliar foreign world. In this atmosphere Elihu, sensitive, eager, and studious, began his schooling and by sheer hard work made a place for himself in a dawning mechanical age.

The new home on Jackson Street was soon visited by tragedy. In midsummer of their first year there, two-year-old Mary fell ill of dysentery and died. Summer complaint was then very common, and there was little doctor or family could do but wait and pray. Elihu stood half dazed in the darkened bedroom with the others, watching for the end, unable to comprehend why it was allowed to happen. He saw only that the doctor had failed, and he was more angry than sad. His scientific instinct told him that childhood death was unnecessary—the forfeit for a contest lost through lack of skill.

In the next six years two more baby sisters were born and died in the same way, and all the family, save Elihu, bore the bereavements stoically, as being the will of God. There is little doubt that these childhood shocks were the basis for a deep distrust which Thomson felt for medical methods all his life. He was invariably suspicious of the scientific competence of doctors and could never intrust his loved ones to them without constantly making suggestions. Again and again he would appear in a family sickroom with a medical book in hand, confronting the doctor with what he had found and urging a change of treatment. The medicos ignored him whenever they could; occasionally they took his advice and discovered that he was right. Though he had no medical training his intuition as to causes was uncannily accurate. Often the heroic measures he practiced on himself cured him without recourse to doctors at all.

In the fall of 1859 Elihu Thomson entered the "alphabet class" of a near-by school. When the overburdened teacher found that he not only knew his letters well but could actually read, she set him the task of coaching the others. Elihu accepted the assignment gravely. Seating himself on a desk top with alphabet

card in hand he went to work as if he had been teaching for years.

It was a difficult assignment and the odds were heavily against him. He was slight of build and an annoying British accent still lingered in his soft Scotch voice. But he made a go of it and his success was a pure triumph of knowledge and personality. Under the gentle force of his explanations the "try-and-make-me" attitude of his ruthless little contemporaries quickly dissolved; he actually made them learn the alphabet and like it.

Facing them from the high desk top, small Elihu discovered that he could teach. It exhilarated and delighted him, though he was not aware how he did it. But as the years went by and he became a teacher to everyone he knew, the secret was revealed to others, if not to himself. Even at six he possessed great natural dignity—a dignity of mind rather than body. As he grew up this became the foundation of his intercourse with all the world. He spoke always with unmistakable self-confidence, never weakening himself by guessing when he was not fully informed. When he was ignorant he admitted it with candor, and the charm of his humility lent strength to his already great knowledge. He never intruded with information and would often stand silently while other scientists argued with one another. But such a scene usually ended with someone saying, "Now let's ask Professor Thomson. He'll know the answer." He usually did.

Having taught school successfully on his first day, Elihu soon developed a love for the whole process of learning. He quickly passed the primary grade and was sent to a secondary school in another street. The studies leading up to grammar school were much more difficult, but the harder they grew the better he liked them. His marks were good and he was never absent unless sickness made it absolutely necessary.

Here was the first of many interesting contrasts with Tom Edison, that other great figure who was coming upon the scientific scene at this time in a small town in Michigan. Tom hated school. His formal education was a failure and he abandoned it before he was eleven. His brilliant mind was a mystery to his unimaginative teacher, who finally called upon Mrs. Edison to tell her that the boy was "addled." Thereupon young Tom was removed from the unsympathetic atmosphere and instructed at home. At the time

when young Thomson was becoming an able scholar at the age of seven, Tom Edison was selling papers on the Grand Trunk Railroad and blowing up a chum with Seidlitz powders in a classic attempt to make him fly.

Superficially Edison's example argues that early failure is a requisite to greatness, and there are many who believe it. Actually it proves only that genius is a law unto itself. Elihu Thomson was primarily a discoverer but with a generous share of the inventor mixed in. Edison was no discoverer at all but a teeming beehive of ideas with a mechanical imagination superior to any in history. Throughout their lives the two continued this contrast, Edison plunging into his problems with headlong energy and a staggering score of misses as well as hits; Thomson speculating upon his problems, thinking his way carefully through to sound theoretical ground, then basing upon it brilliant practical solutions which almost never failed. Each admired the other for the qualities he did not himself possess.

Young Elihu was tough and wiry though not robust. Soon he was living Philadelphia life as the boys in the neighborhood did—whipping tops, playing marbles, and exploring the city for romantic and dangerous adventure, insatiably curious as to the reasons for everything he saw.

The great outlet for youthful energy in that day was through the hilarious activities of the volunteer fire companies upon which the city depended. Each district privately supported its own organization, under such resounding titles as "The Moyamensing," "The Weccaco," and "The Shiffler." The alarm of fire was the eagerly awaited signal for pandemonium to begin. Every loyal boy and man within earshot would instantly drop what he was doing and race through the streets behind his beloved apparatus, yelling like an Indian and blowing off the animal spirits that had been pent up since the last fire. Elihu ran with the Moyamensing crowd, which took its name from the Moyamensing Prison a few blocks from his house. A long time afterward the former Philadelphia boy still looked back lovingly on those days of excitement, as his description shows:

> When the alarm had struck, the companies all around immediately gathered their adherents for the run to the fire.

The hose carriages were drawn by the members running out and catching hold of a long rope, while at the head of this curious procession was a man in fireman's helmet and cloak, carrying a great speaking trumpet, through which he bellowed encouragements at his men. The trumpets were the most prized possessions of every company, often made of solid silver and donated by some influential politician, and were used at the scene of the fire to bawl out orders such as "Pass on the water for the Shiffler hose!"

On the way to a blaze it often happened that two companies would arrive at a given street corner at the same moment, whereupon the fire was instantly forgotten as the opposing memberships tried to outdo each other and take the lead. Invariably this brought on a free fight, sometimes ending in the wreck of the apparatus of one or both contestants and not a few broken heads. The heavy silver trumpets did their full part on these occasions, as their badly battered state usually testified.

The small boys of the city were no less violently partisan than their elders. When two young strangers met, be it by day or night, they would immediately square off and challenge. "I run with the Moyamensing!" "Oh, is that so! Well, I run with the Weccaco!" Whereupon the two would instantly set to fighting and in no time the whole neighborhood would be embroiled. In the open lots down by the Delaware the boys separated into organized bands and did bloody battle with sticks and rocks on every school holiday, keeping it up till one army or the other was driven from the field.

A boy from one fire district was never safe in penetrating hostile territory alone, for he was sure to be set upon by the enemy in force. If he was unlucky enough to have money or other desirable booty in his pockets, he was likely to be robbed as well as beaten.

"Skill with missiles was a very desirable quality under these conditions," Professor Thomson remembered. And well he might, since his route to school for years led him over hostile ground.

"I used to start off in the morning with all my pockets loaded with selected stones. Whenever possible we moved in gangs and chose each day a different route so as to outflank the enemy or, meeting him unprepared, crush him by superior numbers. The journey back from school was executed in the same way."

City life was a trifle lurid then; gang fights often ended in serious trouble. Whenever schoolboy battles got important enough the older crowd took hold on both sides, sometimes with pistols and shotguns. It was not uncommon for the casualties to require hospital treatment. During Civil War years district hostilities got so far out of hand that fires occurred with suspicious regularity on Saturday night. Many thought they were incendiary blazes set to ensure a free-for-all fight. The owners of the burned buildings protested in vain until public pressure gradually forced the boisterous volunteer system off the streets and put a paid fire department in its place.

During this embattled period Elihu's mother showed great resourcefulness and courage in letting her boys run their risks unhampered. She was thoroughly aware of their dangers but chose to meet emergencies as they came rather than prevent them.

One day Elihu dashed home screaming and nearly blinded. A gang of boys had challenged him, then lured him to a knothole in a fence and blown lime into both his eyes. The mother did the one thing that saved his sight. Holding his head firmly back, she ran her tongue over the burning eyeballs and licked the lime away. Elihu was in bed for days, but she kept him busy by reading to him and planning future exploits. When he was well again he had no fear.

In those years when Mrs. Thomson acted as both mother and father to her little brood, she watched and nurtured their mental growth constantly and taught them always to carry their projects through. Elihu never forgot a little verse she taught him then.

All that other folks can do,
Why, with patience, may not you?
Always keep that point in view,
And try again.

There was not a day when she did not find time to read aloud of the adventurous history of America or tempt their interest with some exploration into natural science. The date of November 14, 1867, was one that Elihu was thankful for ever after, because of his mother's devotion to the scientific cause. Twelve months before, a fine shower of meteors had been seen in England, and it was expected to return now in even greater splendor.

Sending the boys to bed early that night Mary Ann Thomson stationed herself in the back yard and took up her watch upon the heavens. Hour after hour passed and not an object moved. It got very cold and she wondered if there was some mistake. But she resolved to stand there through the night to make sure. At last at four o'clock the first meteors streaked across the sky. The delighted mother ran into the house and got her three boys dressed and out, just as the full glory of the celestial show began.

Then for two hours they stood, fascinated spectators to the greatest meteor display ever recorded. The whole vault was suddenly ablaze with trails of silvery light as the hundreds of mysterious bodies burned their way into the atmosphere and were consumed. In a constant succession they came, until Elihu believed that the air was alive with the faraway roar of explosions. Not until dawn did the tired but happy woman relinquish her hold upon her sons' hands and let them go back to bed.

On this night began Elihu's deep interest in astronomy—an interest which increased steadily with the years and culminated in many important inventions having to do with telescopes and optical physics. Many times afterward he insisted that his mother's rare courage on that night in 1867 was responsible for his love for the world of the sky.

3

Elihu was eight years old when Fort Sumter was fired on, and he was fully alive to the excitement of the times. His first glimpse of real war came one day when he saw a caravan of heavy carts moving down the street toward the Moyamensing Prison, packed with Confederate captives. "I remember feeling very sorry for them," he says. "Everybody said they would certainly be shot and I could not see why men so tired and bloody had to be treated so cruelly."

Next door to the prison stood Jackson's fireworks factory. As soon as war began this was converted into an ammunition plant. Elihu spent hours at the gates watching the wagonloads of cartridge boxes going off to the front. Stories were soon rife that spies were trying to blow the factory up. One day when Elihu was in his third-floor room in the next street, there was a sudden terrible concussion which rocked the house and pitched him to the

floor. He scrambled to the window and saw across the back yards a huge ring of black smoke shooting upward from the plant, keeping its circular form to a great height. Immediately other heavy explosions followed. As Elihu gained the street the factory became a volcano, belching people and boxes of ammunition into the air. Pandemonium and terror reigned for the rest of the day and night.

When the volunteer fire companies had at last controlled the conflagration, Elihu and his friends poked through the ruins, finding whole boxes of cartridges apparently intact but with the powder burned clean out of every one. They also saw a long leather boot with a man's leg dangling out of it. This was Elihu's first glimpse of public disaster; so deeply did it impress him that he later developed an abiding anger toward those who treated natural forces carelessly. Especially did he become a crusader against the negligence that caused fires. This was natural, for he was growing up at a time when great conflagrations were constantly breaking out everywhere.

One of the worst of these had an interesting technical background. In 1861 kerosene lamps were just being introduced, as the result of Joseph Henry's long research into lamp fuels for the U.S. Lighthouse Service. Up to that time candles and whale-oil lamps had sufficed everyone except the rich, who could afford illuminating gas. Professor Henry discovered that lard oil and kerosene were far superior, provided they could be vaporized before burning. A cheap efficient kerosene lamp had soon been invented to fill the need.

The sudden demand for petroleum products opened the Pennsylvania oil fields to full exploitation, and kerosene became abundant and cheap. By 1861 the new light was in every home. It was so vast an improvement over candles and whale oil that popular songs were actually written in praise of kerosene.

But the authorities had no notion of the potential danger of storing the oil in the midst of crowded cities. The stuff was simply shipped into town in barrels and piled up in any available place.

Near Elihu's home, there was a big vacant lot in which thousands of barrels of kerosene had lately been stored for lack of warehouse space. The lot was surrounded by wooden houses on three sides, and a gutter in the street ran for several blocks among them before reaching a drain into a main sewer.

"One night," he remembers, "this great store of oil caught fire or was set by an incendiary, and a fearful conflagration resulted. As the barrels on the bottom blazed up those on top burst from the intense heat, flooding the whole vacant lot and filling the street gutters with flaming oil, which ran in all directions for blocks.

"There was no escape possible for the people in the houses surrounded by the burning oil. They were awakened to find walls of flame on all sides and everything but the few brick walls already burning. The firemen were lost in their efforts at rescue. The more water they poured on the more the blaze spread. In no time two whole blocks were consumed, their inmates with them." The aftermath of the fire was a public investigation. A city ordinance was passed forbidding the storage of oil except in walled depressions. Elihu, who was nine at the time, observed the tragedy at close hand and knew that it had been caused by carelessness. He resolved to warn people of the danger whenever he had the chance.

Soon after this he discovered just how difficult it is for people to realize danger in advance. A kind lady had asked the neighborhood children to her house to see a Christmas tree that she had decorated with silver balls and many yards of paper lace ribbon, interspersed with lighted candles. When Elihu entered the room he noticed at once that a candle was about to set fire to the ribbon. He instantly stepped up and blew it out. The lady was much annoyed. "Don't do that," she said. "It is all right."

Elihu started to object but she ignored him. A little later the whole tree suddenly blazed up, sending the children in a stampede for the door. Fortunately the lady kept her head and managed to throw the flaming tree through a window before it set fire to the house. Elihu lingered outside, hoping for a word of commendation. If his warning had been heeded, he knew, there would have been no fire. But the kind lady was quite angry and sent him home without a word.

Chapter 2

I

The school curriculum of the sixties soon proved too slow for Elihu Thomson's able mind. From the first day of the primary grade he had been far ahead of his age, jumping from class to class and delighting one teacher after another. By the time he was ten he had reached the final grammar grade and would soon be ready for high school.

By good fortune the new class was in the charge of a male teacher, George Stuart by name, who recognized at once that the boy was exceptional and did everything he could to advance him. After a winter of most satisfactory progress, Stuart sent his protégé across the city to take the entrance examinations for the Central High School.

Elihu never knew the results of his tests but was certain that he had passed easily. However, entrance was impossible, for no boy could be admitted to high school until he was thirteen. Presently George Stuart proposed a plan; he wished Elihu to drop out of school altogether for two years and build up his health. "Go home and rest," he advised. "Don't study. Don't bother with books at all."

Instead of being overjoyed at this sudden offer of an official vacation, Elihu was panic-stricken. "Am I not even to *read?*" he demanded, and added, extravagantly, "I would rather die than not have my books."

"Read if you like," Stuart agreed, "but don't study. Get outdoors and have fun. You've earned it." Much as he appreciated the boy's talents, he did not realize that to a young mind like this study was second nature, more necessary than play itself.

Elihu went home bewildered, feeling that he had been betrayed. But his mother quickly reassured him; he should read everything they could lay their hands on. He could do wonderful things in those two free years. It was a chance that not another boy in the

city could have—a chance to build things, make experiments, explore! A chance to find out "the go" of everything in sight.

Elihu soon caught his mother's enthusiasm. Mr. Stuart had indeed given him a wonderful opportunity. He would use it to study science—to find out the workings of chemistry and mechanics and electricity. Perhaps he would even be able to discover something new! It was the first stirring of the scientific spirit. To build—to investigate—to demonstrate to oneself the truth of principles already discovered by others—to go in search of new ways of doing familiar things still badly done—to think up new uses for old materials and new materials for old uses—this was the genuine independent mind at work; this was the questioner, unwilling to accept information at second hand, demanding his own answers direct from nature.

His father was scandalized when he heard what his son proposed to do. No boy ought to be allowed out of school at that age. His teacher must be a fool. But the mother only smiled and skillfully diverted her husband's attention. Things were going exactly as she had hoped they would with this brightest of her three sons.

Elihu was immediately an object of envy to his friends and for a time threatened the discipline of his whole class at school. Soon he had introduced a way of making whips for tops and had started a rage for leather "suckers" for picking up cobblestones on a string. Next he popularized the blowgun made of a hollow elder stalk, using bits of potato for ammunition, and followed these with other forms of troublemaker such as delight any boy's heart. It became the habit of his cronies to drop around to Elihu's after school to see what new invention was under way or what fresh deviltry might be learned.

In the course of time Mr. Stuart had to protest in self-defense. If Elihu didn't turn his ingenuity into more constructive channels he would have to come back to school.

"Why don't you try real experiments?" he pleaded. "Build things that work. Look around you and imitate."

It was splendid advice and started the boy in earnest upon his career. There was an iron foundry near by. He resolved to visit it and learn how to make castings of his own. He began the project at once and met with one failure after another. Iron could not be melted on the kitchen stove. Nor could it be worked in a miniature

Elihu's mother, Mary Ann (Rhodes) Thomson

cupola furnace which he made of a tin can. A much larger furnace likewise failed until he abandoned iron altogether and charged it with old type metal picked up in a vacant lot. This melted perfectly. After much experimenting with patterns and moulds he at last achieved a perfect casting—a fairly good imitation of a jackstone. Elated, the boy began turning them out in quantity, till he made them well enough to sell to his friends.

But Elihu's ambitions were high. He wanted to cast a cylinder for a real steam engine. Type metal was no good; it must be iron. And the only way to get the necessary heat was to fit the furnace with an air-blast fan.

Copying diligently from the foundry, he managed to construct a fan out of a round collar box with a wooden shaft through the middle carrying two blades of tin. The pulley outside was a spool and the driving wheel the cover of a cheesebox bought from the corner grocer. The two were belted together with string.

When everything was ready Elihu charged the furnace with bits of iron and coke, then lighted it and began to crank with all his might. After a few minutes he was rewarded with a thin stream of molten iron trickling out onto the kitchen floor.

His elation at this success was short-lived. The mould which he had made for the engine cylinder was too large for the furnace. The iron cooled and hardened long before the casting could be finished.

Elihu's disappointment was intense, but his reaction showed the true instinct of the engineer. He realized that he had been working with the wrong order of magnitudes. No cupola that he could build would be large enough to work. He would waste no more time trying. Cheerfully he filled the furnace up with type metal and fashioned a beautiful but useless steam engine cylinder out of that, just for the sake of rounding out the job. Then he put the whole thing behind him and went on to something else.

Yet the foundry imitation had been an important experience. It was his first piece of research; he had carried it far enough so that he knew the whole subject thoroughly but not so far as to waste time. The instinct for recognizing a blind alley and turning out of it in time is a rare one indeed among inventors. To possess it is to be a scientist. Young Thomson did possess it in extraordi-

nary degree. It saved him hundreds of hours of useless labor in the years soon to follow.

2

All this time Elihu had been reading steadily, absorbing every scrap of scientific material that came within reach. His father subscribed to an English monthly called *The Imperial Journal of Art, Science and Engineering*, and the boy devoured every word of it. The subject that held his attention best in this magazine was photography, which a series of articles explained. Elihu's one ambition now was to make a camera of his own.

The first requisite was a lens. This he hoped he could cast by melting bits of glass in his furnace, later polishing the rough surfaces to the exact figure the articles said was required. But he never did. One day, while breaking up a glass doorknob, he made the wonderful discovery that some of the fragments themselves had the power to magnify. Elihu set to work immediately with a pair of pliers snipping off the irregularities on the glass to make it round. When this was done he devised a wooden handle with a hole in it to hold the little lens conveniently. He had fashioned a serviceable magnifying glass out of vacant-lot junk.

For the time being the camera was forgotten. Soon Elihu was turning out magnifiers by the dozen and selling them for two cents apiece. Then he discovered behind a drugstore a pile of broken bottles whose round bottoms made even better lenses. The business went onto a production basis. Before long Thomson magnifiers were such a rage in grammar school that Mr. Stuart again had to beg Elihu to take up another research.

When the youthful investigator was halfway through the series of articles on photography the war cut off the *Imperial Journal* altogether. Elihu was broken-hearted and begged his mother to buy him a book on the subject so that he could finish his studies. Mrs. Thomson searched high and low in Philadelphia but was told that no such book was for sale. Unwilling to go home empty-handed she bought a copy of *The Magician's Own Book*, hoping that Elihu's interest might be diverted into sleight of hand. But he was not to be consoled.

For some time he was despondent, and then, thumbing through the book one day, he found himself all at once in a new world. This

was no mere collection of parlor tricks but a whole encyclopedia of natural science. After a few chapters of magic came hundreds of pages of experiments with chemistry, electricity, magnetism, light, and sound! There were pictures on every page showing how the apparatus could be made at home.

By sheer good luck Mrs. Thomson had put her hands on a complete elementary text on physics and chemistry—the ideal handbook for the home laboratory of a boy of twelve. It explained combustion and the making of chemical compounds such as laughing gas; it told everything known of electricity and magnetism and illustrated various machines that could be built to demonstrate them; it went into pneumatics, aerostatics, optics, mechanics, hydraulics, and acoustics and ended with a treatise on geometry and numbers and a section on "Practical Puzzles and Paradoxes."

The Magician's Own Book was a turning point in Elihu's life, for it gathered all his vague creative yearnings into constructive channels and showed him the path to real scientific knowledge. Morning, noon, and night he was buried in its pages. Soon he knew every word, almost by heart, and understood the principle behind every experiment. Again and again in later life he fell back upon this splendid course of training, not only in science but in the arts of magic and ventriloquism, which he had mastered along with the rest. His children and grandchildren remember him best for the stunts and experiments he did for them on countless occasions, most of which originated in *The Magician's Own Book.*

By this lucky turn of fate was Elihu Thomson's scientific career begun. A similar good fortune had served many others in their youth. Joseph Henry's career in electrical discovery had been started by a book. So had Faraday's. Not much different was Maxwell's or Pupin's or Edison's.

Henry at thirteen was an apprenticed watchmaker, a trade which he hated and planned to abandon for the stage. One day he happened to pick up a book called *Lectures on Experimental Philosophy*, which a boarder at his grandmother's house had left open in the parlor. He began to read it casually but was soon so enthralled that he kept on to the end without stopping. The lectures opened a new world to Henry. Eagerly he entered courses in science at the Albany Academy, graduated with high honors,

and became its professor of chemistry. He was shortly the foremost American scientist of his day.

Faraday's case was remarkably similar. He was apprenticed at fourteen to a London printer and had to do the bookbinding for the establishment. He disliked this as much as Henry did watchmaking. One day an encyclopedia came in to be bound, and Faraday chanced to read its few paragraphs on electricity. His future suddenly became clear. He began attending the public lectures on chemistry which Sir Humphry Davy was giving at the Royal Institution and made such excellent notes on the discourses that Davy hired him as his private assistant. In a few years Faraday had become the greatest name in British science.

3

Elihu Thomson at twelve disappeared into the depths of "experimental philosophy," determined to make it his profession. At first electricity interested him to the exclusion of everything else. Its mysterious action offered limitless possibilities for experiment and discovery. On page 127 of *The Magician's Own Book*, for instance, he found an article on "How to Make an Electrical Machine," which began:

"It is very easy to make a glass machine of the cylindrical form if the maker cannot afford to buy one . . . ."

Magic words to a boy with skillful hands! All that was needed was a wine bottle, a spindle and crank, a leather pad, and a piece of silk. The article assured the young reader that he could not fail if he followed the simple directions. Once made, a wealth of experiments with sparks lay before him, among them "The Electric Kiss," "Imitation Thunderclouds," and "How to Draw Sparks from the Tip of the Nose."

For several weeks Elihu was occupied with the difficult business of boring a square hole through the bottom of a wine bottle, then mounting it on a shaft to revolve accurately against a leather pad when a crank was turned. At length all the problems were solved and the homemade friction machine was ready. With the first turns of the shaft the young scientist was rewarded with a beautiful electric spark almost half an inch long.

To make the sparks stronger Elihu next followed the directions for constructing a small Leyden jar and found that the book was

wrong in promising that all glass was a good insulator. Fruit jars of a pink color would not hold electricity at all. He had observed enough of glassmaking to figure out that the iron salts in them made them leak. Thereafter he searched for and used only jars of pure white.

Soon after the outfit was ready Elihu's father returned from a trip to Cuba and asked him what he had been doing with his time. "I'll show you," said Elihu, and ran off upstairs to fetch the electric machine. Daniel Thomson did not like praising a child if it could be avoided. So, when the machine arrived, he looked at it casually and dismissed it with a slighting remark.

"You wait!" said Elihu, and gave the crank a few quick turns. "Now touch the pole of this Leyden jar!"

"And why not?" cried his father, doing so. The jar gave up a feeble charge. Daniel Thomson looked around in mock surprise. "Well?"

"Didn't you feel a shock, father?"

"Oh, now, was that pinprick a shock?" And he burst out laughing.

This was a challenge not to be ignored. Elihu retired to his bedroom workshop to find a way to give his father a real shock. Obviously one small Leyden jar was not big enough to store the necessary electric energy. He would have to use half a dozen instead. Not having the tinfoil to make them, he tried immersing the jars in a bowl of water and partly filling them with it also, and he soon had a powerful Leyden battery of his own design.

One snapping cold night in midwinter he set the stage for his comeback. "I cranked the electric bottle machine hundreds of times and got a real charge in my battery," he says. "Then, most innocently, I requested my father to attend the experiment and complete the circuit. He did so readily, believing that this time he would put an end to my foolishness."

What happened frightened even Elihu. The shock threw Daniel Thomson into the air and landed him on his back, where he lay cursing till his wife ran in and picked him up. "I'm sorry," said Elihu hastily. "I didn't mean to make it so strong." His father was on his feet again directly and stood staring at the machine, rubbing his tingling arms. The boy waited, sure that

this was the end of his laboratory at home. Then his father held out his hand.

"Sonny, I was wrong. I'll never laugh at you again."

"Then I can keep on?"

"Not on me, you can't. But I'll tell you what I'll do . . . ."

Elihu was elated. This was the first time that his father had ever taken him seriously.

The crude little wine-bottle machine, now nearly eighty years old, can still be seen today in Professor Thomson's office-museum in Lynn. It is a remarkable piece of workmanship; more, it is an important historical monument, for it is the first practical device built by the man who became one of the greatest electrical inventors of his time.

4

From *The Magician's Own Book* Elihu next learned how a telegraph was made and how to set up the "galvanic" or chemical battery to run it. This led him to experiment with the innumerable mysteries of chemistry and physics that crowd the background of the everyday world—how to make dyes, gunpowder, hydrogen and oxygen gas; how to electroplate spoons; how to perform the magic of magnetism with iron filings; how to make a compass needle; the beautiful little experiment of the Cartesian diver; the theory of the spinning top; the principle of the thermometer and mercury barometer; how to talk over a stretched string by means of the "lover's telephone"—all the hundreds of tricks and demonstrations that had gradually gathered through the centuries, the bequest of countless men of science.

All these things Elihu tried and by trying taught himself the fundamentals of the physical world. There was no limit to what he could do other than the bounds of his own skill and patience. The dangerous forces he might release depended solely on his own judgment and natural caution. He did not actually risk his life, but he got splendid training in invention from the constant necessity of finding and adapting his own materials. That, more than any other thing, taught him to study and understand the exact principle of the apparatus he was trying to build.

The fashioning of a bent nail to make an electromagnet for his telegraph was not a serious problem. But the insulated wire for

winding the coil upon it was a thing he could not obtain. So he made his own, by winding cotton thread on bare wire. It was an invention for which he could well be proud. Joseph Henry himself had done the same thing—and quite as crudely—as a professor at Princeton College.

When the telegraph was successful Elihu's interest in experimental science temporarily abated. He had built all the machines and done all the experiments possible. Now he turned to sleight of hand and ventriloquism and spent a short interval trying to educate a parrot his father had brought home from Puerto Rico; then gave up when it would not learn the multiplication table, and went in for the mechanical arts. With his father's help he got permission to hang around the Philadelphia Navy Yard not far off. There were fascinating things going on there, among them the building of the *Tonawanda*, the first conventional battleship in the United States Navy to be armored, and one of the earliest to be driven by Ericsson's screw propeller.

The yard was seriously short-handed. After a good deal of pleading Elihu got the job, for an hour each noon, of running the donkey engine which bored the holes for the propeller shafts in the battleship's stern. He was a proud and happy boy to feel that he had a real part in winning the war for the Union. For weeks he spent all his time at the yard, watching every operation of shipbuilding, especially the installation of the great slabs of armor plate along the *Tonawanda's* water line. He heard that armored vessels were expected to win the war.

Those were unhappy times in Philadelphia, marred by such strains as the Battle of Gettysburg, which held the near-by city in terrible suspense for three days. The joy that ran through every home when it was known that Philadelphia was safe caused such jubilation that great crowds sang in the streets and the fire companies celebrated with the best free-for-all fight in years.

But the most indelible impression that Elihu brought with him out of those dark years was of the afternoon of April 22, 1865, when the body of Abraham Lincoln lay in state at Independence Hall. Everyone in Philadelphia went to gaze upon the wonderful deep-lined face and assume a share of the nation's grief and resolution for the future. Elihu joined the crowd with his mother but was soon separated from her and never reached the hall.

In the mass of straining humanity he was nearly crushed to death.

That fall, at the age of twelve and a half, he went back to school to take his final examinations for the Central High. George Stuart had been moved to a school two miles away but he insisted that Elihu follow him there, and the boy was glad to do it in spite of the long daily walk. Soon Elihu fell into the habit of visiting his teacher at his home in the evenings, where they discussed his future thoroughly. Elihu told him he was sure now he wanted to be a scientist.

"You will have to study very hard," Stuart warned him. "You will have to study all your life."

"What does that matter," cried Elihu, "if I can learn how to invent new things?"

"But are you sure there are enough new things to invent?"

"Yes! Thousands! Take electricity, for instance. Think of what it will do if its powers can only be controlled and used!"

One day Mr. Stuart kept him after school and took him to a big cabinet whose glass doors were always locked. Elihu had stared through those doors many times at the wonderful array of apparatus within: friction machines, electromagnets, galvanometers, and all the rest. Now Mr. Stuart unlocked the doors and lifted the treasures out, one by one. And they stayed far into the night to play, to question, to remember, tramping happily side by side with the great scientists of the past.

Chapter 3

I

Science did not reveal itself, fully developed, to the philosophers of old —a complete art to be handed down through the generations. It came, bit by bit, a growing mass of unrelated and often contradictory facts, confused by misconceptions, superstitions, silly lies. For three hundred years the pioneers hacked their way through the wilderness, adding gradually to the sum of their basic knowledge—three centuries filled with the work of many unselfish men, great and small, who struggled on because they passionately loved the truth.

Yet it is amazing to see how early the kernel of that truth was recognized and how little the work of the first great geniuses has been modified since. As far back as the late seventeenth century Isaac Newton established the complete mathematical theory of gravitation and discovered the basic laws of light and color. In the same period Kepler explained the motions of the planets and formally proved the discoveries which Galileo had made with his crude telescope.

All three of these early searchers used the heavens as their laboratory. The movements of the stars and planets, indeed, posed the first problems to occupy the great investigators of that time. Men could learn more in the depths of space than in their own workrooms, for the telescope was almost the first precision instrument they had. With it and the ancient tool of mathematics the larger principles of the universe began to take shape, while the details remained locked away in the substance of the earth under foot.

The stars had always been friendly. They had been the first to give man a glimpse of the size of his universe, the first to inspire his poets, and now the first to show him the path toward truth. Centuries later they would help again, as the assay laboratory in which the real nature of the atom would be revealed. Whenever

the smaller mysteries on earth would threaten to become unbearable, the stars would always serve as a kindly balance to give man courage and remind him of his infinitesimal part in the great scheme.

The eighteenth century was half gone before the philosophers again made advances worthy of Newton's great beginnings. Men were preoccupied with other things: the tremendous experiment in American freedom, the calm and stately beauty of the music of Haydn and Bach, the far-flung explorations of the British sea captains. Only toward the end did Sir Henry Cavendish take up the path into the scientific wilderness. Then, as if a divine hand had suddenly raised a torch to light the way, the new crusaders sprang up everywhere and pushed furiously ahead.

Cavendish was one of the first modern scientists to rely upon laboratory experiment. His method of investigation by painstaking measurement and practical testing of every theory gave an entirely new approach to physical problems. With its impetus chemistry and electricity soon became full-fledged sciences. Using the laboratory method Sir Humphry Davy and others presently proved that the earth was composed of many chemical compounds, ultimately separable into their component elements.

Davy gave chemistry its first popular appeal by a series of public lectures before the Royal Institution in London. He was also president of the Royal Society there. His contemporaries objected to him because he was "too lively," yet it was he who first interpreted science to the common people who would some day benefit from its discoveries. His lectures were models of clarity and beautiful English. They invariably drew crowds, among them such unscientific men as Coleridge. "If Davy had not been the first chemist," Coleridge said, "he would have been the first poet of his age. I attend his lectures whenever I am able in order to increase my stock of metaphors." Here was the first rent in the dark cloak of magic with which the bogus philosophers had sought to disguise their ignorance for centuries.

Electricity was meanwhile struggling to throw off the age-old misconception that it was a fluid, something like water, but invisible. It had been known vaguely to the Greeks and to the centuries that followed as a substance, intangible but real, that

could be rubbed from the surface of certain hard bodies and deposited on light balls of pith to make them mysteriously repellent to one another. It was known to William Gilbert, physician to Queen Elizabeth, who spent a lifetime investigating charged bodies, to which he gave the name "electrics." It was Gilbert, indeed, whose great treatise on magnets and the magnetism of the earth earned him the title of The Father of Electrical Science.

A century and a half of experimentation after Gilbert, however, did not relieve electricity of its confusion. Separating it into two fluids only made matters worse. "Sulphurous" and "resinous" electricities were needed now to explain the strange effects of repulsion which took place when sulphur and resin were rubbed. The misunderstanding was complete.

It was then that Ben Franklin broke through the fog with his dangerous kite experiment, proving that lightning and the man-made "mechanical" electricities were identical in every way. They were not two dissimilar fluids but only a single form of energy which appeared as "positive" and "negative" charges in thunder-cloud and earth, or on the opposite tinfoil coatings of a Leyden jar. When the lightning bolt jumped through the sky—or the spark through the laboratory—it was nothing more than electricity in motion, restoring the natural equilibrium.

The importance of the great American's experiments lay not at all in his dramatic coaxing of lightning out of the clouds, but in the simplification which he was able to make in a concept for so many centuries confused. It was Franklin's belief that all substances contained electricity and that the act of charging a body, either positively or negatively, consisted merely in adding to or subtracting from the quantity of electricity normally present. This theory made electricity a natural force as independent of the substances in which it arose as was the wind independent of the country whence it blew. Definite laws governing this new force could now be sought in the same manner in which those of gravitation had been sought by Newton and Galileo.

No sooner had Franklin made this vital contribution than Cavendish, Coulomb, and others embarked upon careful researches to establish the mathematics of the electric charge. The foundations of the new science were ready to be laid.

But the confusion was not over. Discoveries have never come

in the order in which they can best be understood. Just as the riddle of frictional electricity was clearing itself, a mysterious connection was found between chemical solutions and the electric current. It appeared that there was another form of electricity which did not exist *except* in motion and so refused to fit Franklin's concept of the electric charge.

In 1780 Galvani, an Italian professor of anatomy, was mystified to find that a scalpel touching the exposed nerve of a frog's leg caused the muscle to contract. He had noticed before that a shock from an electric machine would cause muscular spasms, but this was different. No outside influence was present. Though the cause seemed to be electrical, its origin was obscure. The current arose spontaneously from the contact between the tissues and the knife.

Galvani searched for the answer in vain, but a contemporary, Alessandro Volta, had better fortune. In a brilliant series of experiments he showed that a weak but steady electric current could be generated by chemical action. After a long search his work culminated in 1800 with the epoch-making invention of the chemical electric cell.

Volta and Galvani shared the honors; the new electricity was called "galvanism," the battery the "voltaic pile." Chemists everywhere began to study the electrical action of dissimilar metals in acid solutions. A steady current could now be made to flow as long as the chemical action continued. The world's first source of electric power had been discovered.

2

The nineteenth century opened with a tremendous drive in the electrical field. Under the skillful hands of Sir Humphry Davy, Wollaston, and others, the power and efficiency of the chemical battery were rapidly improved. Using heavier and heavier currents, Davy soon discovered the reverse of battery action—electrolysis—and was able to decompose water into its constituent elements, oxygen and hydrogen. Carrying the work a step further, he broke down various chemical salts and produced for the first time metallic sodium and potassium. Then, using a gigantic battery of two thousand cells, he demonstrated before the Royal Institution in 1810 the brilliant light of the electric arc.

Meanwhile, in laboratories everywhere, ingenious scientists were trying to discover the nature of the electric current itself and to formulate the laws governing its actions. Early in the search an obscure Austrian named Romagnasi observed that electricity flowing in a wire would turn a near-by magnetic needle out of its northerly course. Magnetism had long been suspected of some mysterious affinity for electricity; here was proof. But this man failed to realize the tremendous importance of what he had found and dropped the experiment. Not until 1819 did Hans Christian Oersted rediscover the electromagnetic effect and publish it to the world.

Excitement was intense throughout Europe; everywhere experimenters hurried to follow this new lead. Within a year Ampère had found that a magnetic force was exerted between two wires carrying current. Arago observed that a copper disk turned only reluctantly between the poles of a magnet, though copper was well known to be nonmagnetic. Young Faraday, just beginning his career as laboratory assistant at the Royal Institution, showed that a revolving magnet would drag a copper disk around with it. Sturgeon produced the first crude electromagnet, wound with bare copper wire, and Joseph Henry, working at Princeton College, improved the device so greatly by insulating the wire and increasing the number of turns that his magnet could lift a thousand pounds. Then came the first practical application of electromagnetism: the galvanometer, for measuring the strength of the electric current—an instrument indispensable to all further research.

And finally, in 1827, Georg Simon Ohm discovered the fundamental relations between current, voltage, and resistance in an electric circuit—the first basic law of all electrical science, soon known as "Ohm's law." It was expressed by the simple formula

$$\text{Voltage} = \text{current} \times \text{resistance}$$

The background of electrical science had now been sketched in. But it was not yet complete. So far experimenters had proved only that electric currents generated magnetism. No one had thought to ask whether magnetism might generate electricity.

This far more difficult problem was attacked by Faraday and Henry about the year 1831, independently and without knowledge

of each other's work. The result was a complete electromagnetic theory that explained not only electricity but light, and gave promise of containing the secret of the whole physical world.

This triumph of pure research showed the philosopher at his best, pitting all his intellectual strength against nature and by sheer feats of inductive reasoning beating her on her own ground. Both these great men were utterly selfless, interested only in tracking down the facts and distilling from them a fragment of the universal truth. As Elihu Thomson heard the story from Mr. Stuart's lips he realized what magnificent humility the philosopher must have and how rigidly he must discipline himself against accepting doubtful evidence, no matter how desirable it might be. He saw what Charles Darwin had meant when he said, "I have steadily endeavored to keep my mind free so as to give up any hypothesis, however much beloved (and I cannot resist forming one on every subject), as soon as facts are shown to be opposed to it." He understood why Faraday, the moment he had discovered something new, racked his brain for ways to show that it wasn't so, calling it a fact only when every possible objection had been answered. The pursuit of science, indeed, required the highest standard of personal honor in the world.

Michael Faraday came to the Royal Institution in London as Davy's lecture assistant. But he quickly showed that his own talent for discovery was greater than his employer's. Within a few years he himself had become the director of the laboratory and had begun his career as the most beloved scientific lecturer in Europe. In the fall of 1831, in six weeks of intense experiment, he made the fundamental discoveries that established the theory of electromagnetism.

Faraday had long known that an electric current was always accompanied by magnetism. Whenever electricity was sent through a coiled wire magnetism collected at its center. If a bar of soft iron was placed in the axis of the coil it became magnetized —identical for the time being with a permanent magnet made from the lodestone. But instantly the current ceased the magnetism ceased also.

So much had been observed again and again. But now Faraday asked himself the vital question: "What *becomes* of the magnetism

when I shut the current off?" Reason told him that its energy did not disappear without a trace. "Where, then, does it go? Back again into electricity perhaps?" To answer this he devised a simple experiment. Placing two coils of wire around an iron bar, he connected one to a galvanometer and sent a current through the other. Then, as he watched the magnetic needle closely, he broke off the circuit to the battery. The needle jumped violently. Here, then, was the lost magnetic energy, transformed back into a sharp electric impulse when the current which had created it ceased.

Forgetting to eat, forgetting to sleep, Faraday hurried on to other tests. For several weeks he worked day and night in his laboratory, trying every possible variation of the experiment to see if there was a fallacy in his reasoning. There was none. At last he was ready to devise a second series of tests. For years he had tried to change magnetism into electricity by placing a permanent magnet in a coil of wire and looking for indications of a current in a galvanometer connected to the coil. Nothing had ever happened. Now, in the light of the recent discoveries he suddenly realized that electricity did not result from magnetism at rest but from magnetism subjected to change. Electricity in motion generated magnetism; magnetism in motion created electricity. He named the phenomenon electromagnetic induction.

Hastily he thrust a strong bar magnet in and out of the coil. He was overjoyed to see his galvanometer needle respond to every thrust. With a series of swift motions he could cause it to spin around completely. He laughed aloud. For ten years he had worked with this same apparatus but had never thought of moving the magnet until now.

Next Faraday made the great leap from experiment to theory that only genius can make successfully: he visualized the actual shape of the magnetic area stored around a coil that was carrying current. This he called the "magnetic field" and conceived as a space filled with "lines of force." The names as well as the concept were his own. These lines were, he believed, like tiny threads, wound continuously through the center of the coil and around the outside till they completely enveloped it inside and out. The magnetic field around a coil of wire resembled a lady's muff, the coil being enclosed between the layers of fur.

Faraday reasoned that the number of magnetic lines in any area

must depend upon the strength of the current and number of turns in the coil—a weak current meaning few lines, a strong one many lines in that particular area. So, when a change was made in the strength of the current the lines, in effect, moved, crowding together or thinning out in response to the force that generated them. The result was that the lines cut through the wires of the coil. It was this cutting action, Faraday thought, that induced a "secondary" current in the coil or in another coil near by at the moment of breaking the circuit.

To confirm this view he tried the effect of turning *on* the current, hoping that the rising magnetism would produce a quick surge of secondary electricity just as the falling magnetism had done. It did. That seemed to coroborate the theory; one more test would prove it. Going back to the old copper-disk experiment he placed such a disk on a shaft and revolved it rapidly between the poles of a horseshoe magnet. When the shaft and rim of the disk were connected to the galvanometer, a tiny current was found to flow as long as the rotation continued.

Historically, this was the most significant result of all. Electricity could be generated by moving a conductor through a magnetic field. This crude machine was the original ancestor of the dynamo. Its date of birth was October 28, 1831.

In a few crowded weeks Michael Faraday had done the work of a lifetime. He had invented a practical machine for making electric current and had established a theory to explain the electromagnetic field. The two together were probably the most important contribution ever made in the field of science.

His work had been a classic of pure research, unsurpassed in the simplicity and power of its deductions. Its pattern was typical of all great investigators through the ages. From an unexplained observation, a question; from pure reasoning, a tentative answer; from that answer, a series of experiments designed to test the strength of that reasoning. Then from the results, a theory; and from the theory, a fundamental law to explain the original observation—a law to be tested in many hundreds of critical experiments by countless independent workers, all skeptical, till finally no doubt remained and it passed from fact into a tiny fragment of the universal truth. That, in its essence, was science.

The world found the electromagnetic theory a most difficult

thing to master; Faraday's contemporaries struggled with it for years before understanding it themselves. It remained obscure and unappreciated until James Clerk Maxwell put it into mathematical form and proposed it as the fundamental law of the physical universe. Only four years before Elihu's entrance into the Central High School, Maxwell published his first paper on *A Dynamical Theory of the Electro-magnetic Field*, showing how a magnetic disturbance would travel like a train of waves through space and to infinity. It was so intricate in its conception that only the most skillful mathematicians could understand it. Maxwell himself abandoned a teaching career to devote his entire time to clarifying it, and Elihu saw that for the present it was not for a high-school student to comprehend but simply to take on faith. But he realized that in the applications of electromagnetism must lie the future of natural philosophy.

How little he dreamed that at the age of nineteen he himself would make the first experimental step toward applying Maxwell's theory to a practical invention some day to be called "wireless."

3

The work of Joseph Henry was similar, though less concentrated because of his duties as a professor at Princeton. Faraday published his first observations on induction early in 1832, but the paper did not reach America for many months. Meanwhile, Professor Henry was exploring the same ground with experiments virtually identical. It was impossible to tell which of the two men had made the fundamental discovery first. When Henry read Faraday's paper he realized that he had already produced the same effects and hastened to publish his notes, most of them taken before Faraday took his.

Henry's original interest had been in electromagnets, and it was he who first discovered how to wind them with many layers of insulated wire to make them more powerful. It was he, indeed, who had built a magnet so sensitive to weak currents that it would swing the tongue of a bell when supplied with current through a mile of wire. This was the first telegraph, an instrument which Henry did not think valuable enough to develop.

One day he was experimenting with an iron bar laid across the poles of a horseshoe electromagnet. The bar had a coil of wire on it.

By chance connecting this coil to a galvanometer, he was surprised to see that an electric impulse was produced when the main magnet current was cut off. Immediately Henry sensed the importance of the observation and set out to discover the nature of what he also called "induction." Like Faraday, he searched his memory for previous observations that might help.

He had often noticed that a bright spark was produced on breaking the current to a coil with an iron bar through its center. Without the iron no spark would be seen. What was the spark? Obviously, it was caused by the magnetism stored in the iron; perhaps it was the transformation of magnetic energy into electricity. By increasing the amount of the stored-up magnetism he found he could increase the spark till it gave a distinct shock. By way of demonstration he assembled his class in physics, had them all join hands, and gave the group an electric shock.

Henry was a master of experimental technique. Now he made a number of coils of different sizes and lengths, and by delicate tests proved that this effect, which he named "self-induction," could be obtained on making as well as breaking the circuit. More—he showed that the induced current flowed one way for a make, the opposite for a break in the circuit. Going still further he proved that by using very long coils iron cores were unnecessary. Induction, then, was not exclusively a property of iron.

It was at this point that he learned of Faraday's similar work. No man was ever more unselfish than Joseph Henry. He insisted that Faraday should accept the credit for the discovery of induction, though he himself had made many crucial experiments needed to complete the theory. At the same time he plunged eagerly into further investigations of his own.

He chose for his main inquiry the effect of induction at a distance. To test this he set up parallel wires in his laboratory, energizing one from a battery and trying to detect induced currents in the other at the moment of make or break. He hoped to corroborate Faraday's final conclusion that electromagnetic waves spread in all directions through space. The investigation lasted nearly eight years. Gradually he separated the wires more and more until he was able to create an induced current 220 feet away. The wave energy traveled through doors and floors and

even brick walls. In the final experiment it passed from wire to wire through the solid structure of Princeton's Nassau Hall.

At the end of his experiments Joseph Henry used a vertical wire from a tin roof to the ground and found that currents strong enough to magnetize a steel needle were induced in it by a lightning bolt striking 8 miles away. Here was a very close approach to an electromagnetic telegraph without wires, which Maxwell's work later indicated would be possible. But Professor Henry, who might have gone on to tremendous further discoveries, chose to devote the rest of his life to public service. In 1846 he accepted the post of secretary to the Smithsonian Institution of Washington and divided his time between practical researches for the government bureaus and the establishment of the first international foundation for collecting and disseminating scientific knowledge. The work on electromagnetic induction he left to a hundred others who had eagerly come forward to carry it on.

Nor did Faraday follow up his original discovery. A new research into the nature of magnetism itself lured him into an obscure experimental field in which he was still fighting a lonely advance action when he died.

4

While Faraday and Henry, Maxwell, von Helmholtz, Joule, Sir William Thomson, and many others were pushing outward across the scientific frontiers, countless practical men were striving to put their discoveries to work. Ever since Franklin's time invention had been rushing forward. Watt had brought forth the modern steam engine, Hargreaves the spinning jenny, and Cartwright the power loom. Whitney had produced the cotton gin and Newbold the iron plow. Fulton had invented the submarine and Montgolfier the balloon. These things had been accomplished when Volta ushered in the new century with the electric cell. From that moment on the pace increased steadily.

In 1815 Sir Humphry Davy invented the safety lamp which would protect the lives of thousands of miners forced to work in the explosive black-damp underground. At about the same time Fulton launched his successful steamboat on the Hudson River.

In 1833 a Vermont blacksmith named Davenport, reading of Joseph Henry's work with magnets, invented and built an electric

"engine" powerful enough to run a printing press. Others were built in England and Russia and installed in carts and boats. Soon after, Moses G. Farmer, who had made some money by inventing a paper window shade, built a miniature electric railroad on his farm in Maine, then exhibited it at the near-by county fairs with great success.

In the middle thirties the steam railroad began to drive the canal boats out of America, while horse-cars plunged along every city street. It was only 1840 when Sir Samuel Cunard dispatched the steamship *Britannia* on the first crossing of the Atlantic without benefit of sail—and only 1844 when Morse at last sent a message from Baltimore to Washington with his electric telegraph.

Now inventions crowded one another with breathless speed: vulcanized rubber, the automatic pistol, the phosphorus match; the coming of gas light to the city streets and the discovery by Daguerre and Niepce of chemical photography.

Civil War days saw a few crude experiments with electric arc lamps lighted by dynamos; the machines were even used occasionally to operate a primitive form of incandescent light. The telegraph had reached every civilized country on the globe; submarine cables were in service for short distances, and the first abortive attempt to span the Atlantic with electric signals had been made. Petroleum had been "cracked" into gasoline and the heavier fuels; artificial ice had been manufactured by the evaporation of ammonia; food had been packed in hermetically sealed tin cans.

Yet the surface only had been scratched. The development so far had been almost wholly mechanical. The vast fields of chemistry, physics, and electricity had still to be opened for exploitation.

As thirteen-year-old Elihu Thomson discussed all these exciting things with George Stuart on the eve of his high-school career, he felt himself suddenly rising toward the crest of a great wave. The hundreds of scientists, inventors, mathematicians, who had devoted their lives to these great advances, were generating in him a mighty impulse to go forward on his own.

Chapter 4

I

Young Thomson arrived at the Central High School in February, 1866, with 160 other boys. Four years later he graduated as fourth honor man in a little group of eighteen—all that had survived the stiff curriculum.

The school was the equivalent of the modern college. There were fifteen professors, all specialists, and every boy took courses with them all. Failure in any course for two successive terms meant dismissal. Sessions ran from nine till two without a break—five classes of an hour each, one leading directly to the next.

Elihu was well fitted to get the most out of this college atmosphere. Instead of giving slavish acceptance to the demands of his professors he had the mental energy to pursue his own ambitions, yet his eager, kindly nature endeared him to everyone, students and teachers alike. They saw that he had a purpose in life, and they made every effort to assist him.

The Thomsons' home was more than three miles from the High School, and Elihu walked the distance twice a day for the whole four years. He had to carry such a heavy load of books and papers that his mother bought him a leather satchel the size of a small suitcase. With this he trudged back and forth winter and summer, rain, shine, and snow, without complaint. He thought it a point of honor not to take the horse-car unless it was storming so hard that he would actually be late to school. He always walked home, no matter what the weather was.

One of the particular chums he had brought with him from grammar school was a boy named William Greene. William planned to be a chemist, and that so fired Elihu's interest in the same subject that the two boys organized a scientific group and occupied every spare moment with explorations, discussion, and experiment. Many a Saturday afternoon was spent in expeditions to the outskirts to collect geological specimens or in visiting the docks and

factories and taking swims in the dirty Delaware. The meetings were held together by learned dissertations by Thomson or Greene or both and by risky experiments with chemicals coaxed from any apothecary who would sell them.

Experiments ranged all the way from making electric batteries with nitric acid and zinc to painting the platform of the German classroom with fulminate of mercury paste. The professor in that subject was a hated man, and the detonations which followed his every step repaid the young chemists for all the hours of suffering at his hands.

"The Junior Scientific and Literary Society," as the group called itself, presently decided to hold regular discussion meetings once a week, using for its hall a small wooden bathhouse in the Thomsons' back yard. Planks laid across the tub made an excellent lecture platform, while the audience sat on the floor or in the wash basin. The whole building was 10 by 12 feet square and lent a compact sort of atmosphere to the society proceedings. Here Elihu got his first training in public address, conducting meetings and causing some member to give a "paper" for each occasion. After the delivery he led a discussion. The society met for several years in all seriousness and listened to lectures on the various scientific researches it had undertaken. Between times a table full of chemicals in a corner of the building acted as the experimental laboratory.

At the end of his sophomore year Elihu started a handwritten newspaper called *The Universal Journal: Being a Journal of Romance, Art, Science and Literature Generally*. Publication continued every two weeks for nearly a year. The paper was unique among schoolboy effusions, because it sandwiched original scientific observations between the usual thrillers and personal notes. Thus, in the midst of such literary extremes as "The Counterfeiters, or Murder Will Out," there appeared some genuine scientific reporting, the best of which was a series of excellent pen drawings of the world under the microscope. With utmost care Elihu reproduced views of human blood and hair, the point of a pin, a silk thread, and the whorls and convolutions of a fingerprint. It was the beginning of a lifelong habit of his to sketch everything that came into his mind. The language of the pencil became to him what mathematical formulas were to most scientists; he could

diagram anything so that the stupidest layman could understand —or the most critical technician be convinced.

With the help of these extra scientific activities, Elihu's high-school years sped by. There being no undergraduate athletics to distract him, he spent all his waking moments getting on with his job, in class or out. The six-mile daily walk provided the necessary exercise.

His passion for reading had now broadened to include all the scientific information to be found in the daily press. One of the great news stories of the day told of the final laying of the Atlantic cable from Ireland to Newfoundland in the summer of 1866. The two men chiefly responsible, Cyrus Field and the British electrician, William Thomson, were the heroes of the hour.

Eagerly the boy followed every word of the reports—the final arrival of the cable-laying leviathan *Great Eastern* at Newfoundland; the picking up of the broken cable of 1865, lost in mid-ocean, and the completion of a second Atlantic circuit within a month of the first; the jubilees and torchlight processions in New York and London when Victoria and Andrew Johnson exchanged the first telegraphic greetings; the wild joy of the English people when William Thomson and his assistants, Wheatstone and Varley, returned from the battlefronts; the great round of state and scientific dinners in their honor, and the final knighting of Thomson by Queen Victoria.

Most fascinating to Elihu was the story of Sir William's siphon recorder, which had made the cables "fast" enough for commercial operation. In that fall of 1866, Sir William was making some amazing demonstrations of its sensitivity. One Elihu never forgot. Before a splendid gathering of British notables and their ladies in Valencia, Ireland, the great engineer ordered the joining of the two cables at the American end to form a single giant circuit passing twice under the Atlantic. Then he turned to an onlooker and said, "Will your ladyship kindly lend me her silver thimble?" Taking the tiny object, he slipped into it a little strip of zinc and added a few drops of acid to form a minute electric cell. Then, applying the infinitesimal current to one end of the cable and the siphon recorder to the other, he signaled successfully through 3,700 miles of submarine wire.

2

During their senior year Thomson and Greene organized a full-fledged technical society modestly called "The Scientific Microcosm." It published no journal of observations sugared with murder mysteries; it was an adult and serious venture. Membership soon included every boy in school with a scientific bent.

Meetings were held in the chemistry classroom one evening a month. Naturally enough, the first lecturer was Elihu himself. He chose for his subject, astronomy, and launched into it with all the confidence born of years of addressing his contemporaries. But halfway through, the door opened and several of the teachers walked in. Elihu, at the ripe age of sixteen, was consumed with embarrassment. For the first and last time in his life he knew what it was to have stage fright. Then he gritted his teeth and went on.

Afterward, the professor of astronomy came up to him, obviously pleased. "You kept your head and did admirably," he said. "We were all greatly edified."

This triumph was so heartening that Greene and Thomson decided to take the Mircocosm into the commercial market. The meetings were moved to the school auditorium and the general public was invited to attend. The boys began charging admission and using the proceeds to put up posters in the horse-cars. Soon prominent men were hired to speak. Philadelphia took naturally to such activities, for it was rich in the scientific tradition. The American Philosophical Society, founded by Benjamin Franklin in 1743, still occupied its original building next to Independence Hall. And the Franklin Institute was only a few blocks away, already forty-five years old. Both were focal points for intelligent thought and discussion. The little Microcosm brashly entered the field against this august competition and became an immediate success.

Presently Elihu was lecturing to audiences of several hundred people without a sign of embarrassment. The experience gave him a poise and self-assurance which was of great value later on. For sixty-seven years thereafter he addressed the most august gatherings in the world and never but once was at a loss for words. That

was at a testimonial dinner in his seventy-seventh year, when for a few minutes he was overwhelmed with the eulogies of his admirers. On that occasion some of the audience remembered the story of aged Michael Faraday in his last address before the Royal Institution. In the fog of a failing memory Faraday had burnt his notes before the lecture. Halfway through he suddenly stopped, fumbled, and became confused. "I am afraid I cannot go on," he said. "I don't remember what it was I intended to say." Men and women in the audience were crying as the pathetic figure stood silently confronting them. Then they rose as a body and surrounded him with all the affection that his wonderful personality had created over thirty years.

After a successful winter of lectures the Microcosm went in for original research, presenting reports on interesting natural phenomena that its membership had observed. The most notable of these was Thomson's paper on the famous hailstorm of May, 1870, which pelted Philadelphia with stones as big as golf balls and broke every window in the city facing west. The society was so pleased with Elihu's analysis of the origin of the stones that it voted to publish the report complete. It was the young investigator's first venture into scientific print.

Two years later a similar storm visited Philadelphia—this time on a Sunday afternoon. Elihu hastened into an open lot to take notes on the oncoming cloud—a priceless opportunity to corroborate his earlier observations. But just as the storm broke he remembered he had promised his mother to attend a near-by Bible class. Mrs. Thomson had been talked into this by a door-to-door canvassing agent and had begged him not to fail. Angrily he hurried to the church and submitted to imprisonment with what grace he could.

As the wind rose and the icy bullets pelted down upon the city, the minister raised his voice to a shout and, with what seemed to Elihu a maniac gleam of triumph in his eye, intoned a chapter from the Old Testament about Jeroboam and the other wicked kings. The more furiously the hailstones rattled against the stained glass windows the louder the minister yelled. Finally Elihu could stand it no longer and made a dash down the aisle for the door. But his way was blocked by the sexton, who stood scowling in his path.

The Bible reading went on and the young philosopher was obliged to hear it to the end.

Elihu was furious and afterward gave his mother almost the only scolding he ever administered to her. The poor woman had made what amends she could by gathering a pailful of hailstones and writing down her observations of the clouds. But these were not enough to erase the insult the church had given his scientific soul. "I never attended that Bible class or any other after that experience," he says, with feeling. In his opinion man-made religion was in a conspiracy to drown out the voice of God.

3

In February, 1870, young Thomson graduated from the Central High ready to enter the world as a scientific expert at the age of seventeen, wondering very much who would care to employ him. Cities like Philadelphia were filled with small factories, all strongly competitive and independent. Usually each one had at its head the inventor of its particular product, who did all the necessary development work with the aid of a mechanic or two. Openings for young men trained in science were practically unknown. Elihu would have to take whatever work offered.

With his father's help he got a minor position, late that spring, in a small concern called the Ironmasters Laboratory, which did testing work for the foundries. The routine work bored him to tears, so much so that he wished he could be back at the telegraph messenger's job which he had tried unsuccessfully the summer before.

Telegraphy in those days was as romantic and adventurous a profession as news photography is today. A swashbuckling fraternity of itinerant operators drifted hither and thither over the country, picking up a key in whatever railroad office they found it, fighting Indians, chasing fires and reporting train wrecks, and burning their fingers with the villainous nitric acid which was always leaking out of the great banks of batteries behind the operating room.

Having previously built a telegraph set of his own Elihu may have had notions of joining this happy-go-lucky group himself. Tom Edison had begun that way and was already famous. At

twenty-one he had explored the country, had patented an automatic printing telegraph and a stock ticker, and had been rebuffed in person by Congress in an attempt to sell it an electric vote-recording machine. Fervently a Congressman had said to Tom, "If there is any invention on earth we don't want down here it is a vote recorder! That ought to be self-evident."

But Elihu was temperamentally unsuited to the breezy life of the singing wires. His brief exposure to them in the Philadelphia office of the Western Union ended in disappointment. He remembers only one occasion—"one of the dreariest nights of my life, in lone charge of that office from dark to dawn. During that whole night there were only two or three messages that were handed to me over the counter for transmission. It was my job to shoot them through a conveyor to the operators' room on the upper floor." He did not even have a uniform. However, before the summer was over, he did function occasionally as a cub telegrapher upstairs, when one of the "regulars" was absent. The fact that he didn't make any headway in the business was clearly due to his own unsuitability to it.

At any rate, his prospects in the Ironmasters Laboratory were poor and his future gloomy. There seemed precious little chance of making a living at anything he wanted to do. Then, out of a clear sky one day in September, 1870, came a letter to the assayer's assistant which read:

> Mr. Elihu Thomson, Dr Sir. Be good enough to call at the School without delay and oblige,
>
> Yrs. very truly, R. I. Riché.

Dr. Riché was the president of the Central High School.

Elihu called immediately, making up his mind on the way that if this was an offer he would take it no matter what the pay or hours of work. It was an offer. He was invited to be the "Adjunct to the Department of Chemistry"; the salary offered, five hundred dollars a year.

At seventeen and a half young Thomson entered the teaching profession as a humble washer of bottles and cleaner-up after the classroom lectures of Professor Norris, the head of the department. But he was happy. Had not Michael Faraday started in just this

way with Sir Humphry Davy, quickly to displace Davy himself? As Mr. Norris was the only teacher in the department, Elihu automaticaly became second in command, and there were actually occasions when he did the lecturing himself. But that was not for the moment important. The main thing was that he had found the kind of work he loved—work that gave him freedom to develop his own ideas and authority to apply them. He plunged into the job with vehemence and before very long was the best loved personality in the school. This came about through his extraordinary mental energy and his gift for seeing the "go" of a matter and explaining it indelibly to others.

Downstairs under the chemistry classroom was a cellar compartment in which scientific supplies were kept. It was Thomson's immediate idea that this should be made into a working laboratory for the students. Norris rather dazedly gave his permission and in a short time was astonished to find that it was a going concern, well stocked with chemicals, and filled with experimental apparatus. Asked where all this came from Elihu said quietly, "I bought the chemicals with the school's money; the apparatus I built myself, at home. There are a lot of experiments the boys can do," he urged. "It's the way I always did and the quickest method of learning a subject."

This was a new point of view to his conventional superior who had taught chemistry successfully all his life with no other equipment than a blackboard and a book. Elihu knew that he was flying in the face of long-established practice, but he was enthusiastically certain that the new idea would work—even though this would be the first high-school chemical laboratory in the United States. His authority for the scheme was certainly sound enough; he had been reading of Sir William Thomson's similar exploit in the University of Glasgow. Sir William had cleared out a coalhole in the cellar and made it into the first college laboratory for physical measurements in the world. If the Englishman could bring the sensitive siphon recorder out of a Scotch cellar, why couldn't he do similar feats in a Philadelphia basement?

In fashioning this new laboratory the young "adjunct" had much more in mind than merely to teach his students the rudiments of formal chemistry. He was already thinking of the work

that he might do there himself—original work that would start him on the road to an experimental career of his own. What particular problem he undertook did not matter. The point was to dig in and find something worthy of discovery.

This lively attitude quickly came to the attention of the professor of natural philosophy, Edwin J. Houston, who had liked Elihu as a student in previous years and now saw possible advantage to himself in befriending him. Houston, although only twenty-five, was locally established as an authority on electricity and physics and took pride in making clever contributions to the scientific journals. He was aware, however, that he did not himself possess any experimental ability whatever, being merely erudite and encyclopedic. This was a serious lack in one who had large ambitions in the field of science.

Houston was, before everything, a practical man when it came to his own interests. And he believed that great things might be done by combining his own knowledge with Thomson's evident originality. Besides, he was drawn to the boy as everyone was. Elihu's keen mind acted like a lodestone.

So Houston proposed an arrangement by which they should experiment together and share whatever benefits accrued.

The offer was a tremendous compliment, and young Thomson seized upon it eagerly. With Professor Houston's backing he knew that his experiments would get an official recognition that might otherwise be denied for years. He counted himself in extraordinary good luck and resolved to use every spare moment for original research. So the arrangement began in utmost cordiality and cooperation. It continued for more than ten years, and its fruits were a group of fundamental electrical patents issued jointly in their names.

But these patents were not the result of equal work. Once Houston had signified his support he sat back and did almost nothing. As a laboratory colleague he was a failure. His only contribution to the team was the writing of reports on the experiments and the signing of them with his own name (which he pronounced to rhyme with mouse).

All through this opening period in his experimental career, Thomson bore this burden in silence, loyally refusing to break the

tie. Once firm on his own feet he would have given much to be rid of the man who had become a dead weight around his neck. But his sense of honor prevented.

Perhaps it was fortunate that he did not get free, for the sense of injustice and the perpetual nuisance of it drove him to attack his problems even more vehemently than he would otherwise have done. By this very ordeal his stature was increased.

Chapter 5

Elihu Thomson was going on eighteen. That first fall as a teacher at the Central High School he set himself a pace that would have killed an ordinary boy but seemed to agree with him so well that he kept it up for the rest of his life.

"Not infrequently," he wrote, looking back with satisfaction, "I would leave home after breakfast and not eat or drink anything until I got home again at eleven o'clock in the evening. My dearest friends were predicting a breakdown due to this erratic way of living, but their predictions did not come off. I have always believed in long hours. It is the only way to get things done."

His school duties kept him busy from early morning till late afternoon, and the six-mile daily walk used up at least two hours more. The only time left for original work was thus at night. But he did not stop to complain. Cheerfully he accepted the fact that a young scientist must always support himself on time-consuming routine work and steal odd hours, usually from sleep and recreation, for his own researches. He adopted the habit of working regularly at night, sometimes in the school laboratory, more often in his own third-story room at home. The family had moved again, to a house on Fitzwater Street which was an elegant mansion in comparison to their earlier homes. And Daniel Thomson had become reconciled to the presence in the house of what he secretly regarded as an alchemist's den.

In his first collaboration with Houston the boy chose to investigate the change of color of chemical compounds under heat. It was a typical piece of pure research. Though without immediate practical value it was a real attempt to add new knowledge in an important field—such a research as a graduate student in chemistry would be given today to complete a thesis. But Elihu was after no degree. He made the study because he had seen compounds mysteriously change color and wanted to know the reason. Houston

liked the idea; if Thomson would make the research and jot down the notes, he would then write up the experiments in the finest professional style and send them to the *Journal of the Franklin Institute*. His name would guarantee their publication.

Elihu did the work at home, spending most of the winter testing some fifty chemical compounds both as solids and in solution. When his notes were gathered he devised a theory to fit the results and took the whole thing to Houston, urging him to carry out his side of the bargain. Houston was delighted and immediately began on the final paper. When it was done he arranged to have it published in the journal, as he had promised. But it was to be printed under his name alone. Thomson received only brief mention in the leading paragraph.

Elihu ignored the slight. He was so elated at having completed an independent research, important enough for professional publication, that the matter of credit seemed too small to argue about. Nevertheless, he resolved that as soon as he could make an independent research of his own, without help, he would take all the risk and seek all the honor for himself.

For a number of years thereafter the arrangement persisted—the boy working in the laboratory, the professor doing the writing and claiming sole authorship. It was a most unprofessional arrangement, even if there was some justification for it. The true scientist prides himself above all else on his absolute honesty and especially on sharing credit with everybody who remotely deserves it. But this point of ethics did not bother Houston at all. He went cheerfully on, always ingratiatingly good-natured but insistent upon his leadership of the team.

Finally, in 1873, Thomson published a paper of his own, which cleared the air and somewhat restored his offended sense of justice. This was an inquiry into the physiology of nitrous oxide, or "laughing gas." He had seen the dentist use the anesthetic on members of his own family and was deeply impressed with its swift and rather dramatic action.

The paper, which appeared in the *Philadelphia Medical Times*, described six carefully conceived experiments to prove that anesthesia was caused by partial suffocation rather than by poisoning. From the looks of the patient, Thomson reasoned that "the effects were the result of true asphyxia, rendered bearable by there

Young Elihu Thomson in his attic laboratory.

being furnished an inert gas with which the lungs can be filled and emptied as often as may be." He compared this to the case of a starving man who satisfies his hunger for a time by eating inert clay and gets along very well if he doesn't have to continue the diet very long. The inert gas, he thought, tricked the lungs into believing they were satisfied, while causing unconsciousness to the patient.

The experiments were ingenious and original. Rigging up a rubber bag such as the dentists used, he filled it with pure hydrogen gas and clamped it over the nose of a friend. Results were immediate. The "patient" breathed rapidly, turned blue, and lost his wits inside of a few seconds. Just as he was about to go unconscious altogether, Elihu removed the bag and gave him air and was glad to see him come to at once. In true medical tradition he then tried the experiment on himself and got the same results. Several more tests showed that the effect was the same as with laughing gas.

The next experiment was more elaborate. It consisted of putting a kitten under a glass bell jar filled with a mixture of hydrogen and oxygen, the latter in the same proportion as in air. The kitten showed no signs of distress at all but merely sat and licked its paws till it was removed fifteen minutes later. But when hydrogen alone was used it became unconscious at once. Elihu took it out and revived it in a few seconds.

He now tried the little patient with coal gas and came very near losing it, for it stopped breathing entirely and had to be revived with artificial respiration. From this he decided that coal gas was a poison instead of an asphyxiant—a fact that was not then understood.

The kitten cheerfully assisted in two more experiments which were forerunners to the modern tests for high-altitude flying. In the first, Elihu used ordinary air in the bell jar, merely reduced to one-fifth of ordinary pressure. "The effects upon the kitten," he reported, "were nearly the same as with pure hydrogen, it soon falling over motionless and insensible." In the second test, he filled the jar with pure oxygen and pumped that down to the same low pressure. This time the kitten remained inside twenty minutes, sitting quietly and without any signs of inconvenience.

His conclusions were simple and direct—genuine contributions to the physiology of the lungs. He stated that:

"1. The insensibility produced by the inhalation of nitrous oxide, nitrogen, hydrogen and rarefied air is due to deficiency of oxygen, of which asphyxia is the result.

"2. The inert gases, as well as a vacuum, are rendered capable of supporting life if a proportion of oxygen approaching that existing in common air is introduced."

This piece of original research proved beyond doubt that Elihu had the instinct for scientific inquiry; more, that he possessed the rare gift of sensing fundamental principles which would have important future applications.

The nitrous oxide paper passed unnoticed at the time, but long afterward Professor Thomson lifted it out of the past in a proposal to the U.S. Bureau of Mines that the inert gas helium should be used by sand hogs and divers to avoid the "bends."

2

At the age of twenty Elihu Thomson was about to step out on the world stage and carry a leading part. His fifteen years in the United States had made him practically a native American in habits, speech, and viewpoint. He was a typical Yankee in everything except the nasal twang, for there was still the softness of the ancestral heather in his voice.

The Thomson family itself was highly typical of thousands in the middle class—God-fearing, frugal, hard-working, and deeply respected by its neighbors. Father Daniel had made a moderate success of his engineering work and now owned several dwellings which he kept for rent. But his illustrious son was rapidly becoming the head of the family.

" 'Lihu," as he was affectionately called, detested the name that had been given him. People were always mispronouncing it "*El*ihu" and having to be corrected. It amused his father on such occasions to see his son fall back upon the Bible. "How do you pronounce Ezekiel? How do you say Elijah? Well, then, how should you sound Elihu?" His sensitivity about this only emphasized a scientific mind ever annoyed at careless logic.

The family had grown large. There were now seven children, ranging in age down to Martha, born the year Elihu made the research on laughing gas. Ever since he could remember there had been a baby in the house—a baby or the death of a baby.

One after another, three little girls and a boy had succumbed—first Mary Ann, then Annie Laura, then Annie Amelia, and finally Aubrey. The doggedness with which the Thomsons had thrice tried to perpetuate the mother's middle name was typical. There was no latter-day squeamishness about them. They liked the name and tried hard to use it. There was no nonsense about the family in any respect. Daniel saw to that. All the children except the two eldest were in school, competent though not brilliant. Daniel junior showed a moderate interest in business and was already apprenticed to a druggist's concern and doing well.

Though only forty-four the father had retired and spent most of his time around the house. Mrs. Thomson's life was not easy, for her husband was short-tempered and erratic. But her ability to manage things amounted almost to genius. She was always singing, always cheerful, always ready to solve her children's problems and share their make-believes.

Daniel's retirement had been involuntary—the result of a serious head injury received in a sugar plant in Cuba. Trying to save a small darky from being caught in the machinery, his foot had slipped and he had hung for several minutes while a flying crank struck him repeatedly on the head. The darky escaped unharmed but Daniel lay near death for six months. Finally, he crawled home to Philadelphia, never to go back.

The injury accentuated Daniel's short temper and love of discipline; he seemed to take delight in breaking up the family fun. He was especially fond of driving the children off to bed immediately after supper, then roaring at them incontinently if they made the slightest sound. With unending patience the mother rearranged the household to suit an invalid husband no longer the breadwinner. The children she kept as much as possible out of his way. But she was always on their side. Once, when the boys had been caught playing pinochle in bed and roundly punished, she tiptoed up to them in the dark and said, "Just lie quietly till your father is asleep, then put on the light and play as long as you like."

Mrs. Thomson's principal care was to keep the way clear for Elihu, whose work she protected against all family hazards. His bedroom laboratory on the third floor was sacred territory, and no one was allowed near it except on Elihu's express invitation. Great things were going on up there on week ends and in the small hours

of the night. Often the younger boys would creep through the hall and stand silently peeking in at the door at their brother, so absorbed that he would rarely notice them at all. Fred sometimes was permitted to help, though Elihu considered him stupid and dangerous to delicate experiments. On rare occasions little Otis, not more than six, was allowed to assist at photography, holding a lamp with a ruby shade while his brother went through the critical operation of coating glass plates with liquid emulsion to make his sensitive negatives. The "dry plate" with its gelatine base had not been heard of then.

Elihu's old desire for a camera had at last been satisfied. He had built the apparatus himself out of a wooden box fitted with a second-hand lens and shutter. His special interest was portraiture, in which he never made a success that pleased him. In the poor light of kerosene lamps the wet plates were deathly slow and required the sitter to hold a rigid position for whole minutes at a time. Elihu needed all the technique of the magician on these occasions. With the sitter in place and the scenery arranged, the lights had to be reduced to the single red lamp while the emulsion was poured as evenly as possible over a glass plate. This was then slipped dripping into the camera and made secure. Then lamps all over the room had to be relighted and the victim charmed into a stationary position while the long interval of exposure took place. That done, development of the plate must follow immediately before the emulsion could dry and shrink.

In spite of the complications Elihu became expert, even taking several portraits of himself posed at a table among his bottles and jars. But his success outdoors was better. Years afterward, when he had become a recognized authority on color photography, he looked back with pride upon a picture of a bolt of lightning which he was among the first to catch.

Young Thomson's interest in optics went beyond photography to the making of the lenses themselves. He loved the thought of doing the beautifully accurate work on glass that was possible with a little abrasive and a bit of rouge. As far back as his thirteenth year he had cast in his cupola furnace a droplet of glass which acted as a microscope lens. But it did not suit him, for he did not know the technique of making its surfaces true. Finally, in 1874, good luck gave him the training he needed.

At an exhibit in the Franklin Institute he was examining some instruments one day when an elderly German turned to him and said, "You are interested in these things, I can see." Elihu eagerly agreed that he was. Soon they were deeply immersed in a technical discussion and it developed that the old man, one Herr Gerhardt, was a skilled optician. Elihu was delighted and plied him with questions. The German answered them without restraint and presently invited him to come to his shop. "Now I tell you all dis," he said confidentially, "but it iss a trade segred. You must not tell anybody aboud it."

All his life long Elihu made instant friendships in this way, but none more useful to his future career than the relationship which grew up with this simple old German artisan, who proved to be one of the finest optical experts in America. The young teacher visited him repeatedly, and presently Gerhardt, with a twinkle in his eye, set him the problem of making a lens. "I wish you to make a microscope objective," he said. "I give you de formulas. You haf only to do the work."

It was a staggering demand. There were to be ten separate lenses in the combination, one of which would be a half sphere a tenth of an inch in diameter—about as big as the head of a large pin. Elihu went home and tackled the job with the crude equipment in his bedroom laboratory. All he had to work with was a small foot-power lathe he had made from a sewing machine, and a few wood tools. But in three weeks' time the lenses were done and he was back in Gerhardt's shop, rather apprehensive lest they would not measure up to professional standards.

The old man set them up in his own microscope stand and looked through them for a long time, mumbling to himself as he adjusted them. "De field is flet," he said presently, "and de color is gute—but it is a little meelkie. You haf not polish enough, yes?" Elihu agreed readily. It was, he admitted, a pretty crude job. Then Gerhardt turned to him and looked at him carefully. "I know," he said, "you haf odder things to do. Vell, I congratulate you. I did not expect you to attembt it at all!" There was in his voice that note which raised the young man to equality—such a note, coming from a master artisan, as makes any scientist proud and happy. For there is no joy like the achievement of a surface in glass which is accurate to those few indispensable millionths of an inch.

In after years Thomson's skill at lens and mirror making was known throughout the country and the telescopes and microscopes from his bench ranked with the best in professional use. It all stemmed from the good fortune of that chance meeting with a great craftsman whose soul was too big to hide trade secrets.

3

Throughout his ten years as a teacher at the Central High School, Elihu Thomson kept up the little laboratory in Fitzwater Street. Though he never could afford any tools except those he made himself, he designed and built some of his most important early inventions in that room, including the historic three-coil dynamo—the forerunner of the modern alternating-current machines.

Nothing born there, however, was closer to his heart than his first organ, which he built complete with pipes, air bellows, and console from such scraps as he could pick up or buy at second hand.

At this time Elihu was a thin, black-haired youth with the face of a musician and the manner of a saint. The intensity of his interest in any subject, his wealth of information, his way of infecting everyone he met with his own confidence and joy of accomplishment—all these things endeared him to layman and technician alike. Year by year his list of friends grew greater and his intimates more devoted.

In the first year of his triumphal progress, however, he was stricken with typhoid fever. The disease was particularly prevalent in the years after the Civil War; small pox had its vaccination then, but the typhoid antitoxin had not yet been devised. There was nothing to do but catch it if you must and survive it if you could. Elihu lost several months' time in bed and was a very sick young man. Week after week went by without improvement, while he tossed with fever and complained at the ineffectiveness of the medical men who called themselves experts. At last he determined to do something to get cool; so when nobody was looking he crawled to the bathroom and held his head under the cold water faucet till he had gained relief.

There was a crisis in the house immediately. Mother and family and doctors came running, and all were certain that Elihu had done himself in. But he laughed at them. The fever was gone; he

felt entirely restored and intended to get up shortly and go back to work. Which he did, in spite of all the doctors could do to keep him an invalid.

This experience made him more impatient with doctors than ever. He had decided that medicine could be as accurate a science as chemistry or steam engineering; he continually argued that common sense and the right treatment would cure illness if only the practitioner were wise enough to use them. He was thus in a perpetual clash with the bedside doctors, who he felt regarded their profession as an art rather than a science.

Soon after his successful bout with typhoid Elihu had occasion to prove this point. William Greene, who had graduated with him, was now studying to be a doctor at the Jefferson Medical College. The two were seeing a good deal of each other; Greene had a home laboratory too, and the young scientists visited back and forth constantly. It was winter; for several months Elihu had been persecuted by a chronic cough which was getting so bad he could scarcely work. No one had been able to help it in the least.

One day he arrived at his friend's place to find the room saturated with the fumes of fusel oil which William was using as a solvent in a research on alkaloids. This poisonous liquid is technically known as amylic alcohol, and its fumes are choking and obnoxious. Greene begged him to get out before his cough was made much worse. Elihu replied that he didn't care. It was kill or cure with the cough now; nothing could make him any more miserable. Then the two got absorbed in the experiments and forgot all about it.

Half an hour later Elihu realized that he had stopped coughing altogether. Somehow the fusel oil had given relief. The trouble did not return for two days. When it finally came back Elihu hastened to his friend and got a small bottle of the oil, which he inhaled through a handkerchief. The cough disappeared again, this time for good.

The discovery made no impression whatever on the doctors whom Elihu consulted. All smiled indulgently and assured him his cure was nonsense. But he ignored this discouraging reception and began trying fusel oil on other sufferers, the first being the janitor at the Central High School, whom he cured overnight. Success among his friends was so consistent that he got in the

habit of carrying a small bottle of the remedy with him whereever he went and did so most of his life. Any time he saw the signs of a bronchial irritation he pulled out the bottle and offered it, and almost invariably it gave relief. Among the people who became confirmed fusel-oil users was Steinmetz, who was as annoyed as Thomson was at the unscientific attitute of his doctors.

When he was eighty years old Professor Thomson was still using the remedy successfully and still trying to get his medical friends to investigate its action. And at last, after sixty years of effort he did persuade a young doctor at the Harvard Medical School to start a study of the chemical. But the old scientist died before there were any results and the research languished.

Every man has his blind spots and is entitled to them. Thomson had his, some of them directly in his own field. One in particular that he looked back upon with great regret was his failure to invent the telephone.

While still in high school he and Greene had often discussed the possibility of a "talking telegraph."

Speaking over a wire, they knew, was not their own idea. One Charles Bourseul had published an article in Paris in 1854, proposing voice transmission by electricity. And in 1869 a German inventor named Philipp Reis had exhibited in Cooper Union in New York an unsuccessful instrument which he called a "telephone." Joseph Henry had been present and was so impressed that he bought one from Reis and took it home with him to find out why it did not work.

In 1870 Thomson and Greene decided to invent a telephone that would not wear out after a few minutes' use, as Reis's did. The principle they adopted was original with them and nearly identical with that which Bell would hit upon six years later. Sending and receiving instruments were to be identical, consisting merely of steel diaphragms placed close to the poles of electromagnets, whose windings were connected by a stretch of wire. Speaking against one diaphragm, they thought, would generate fluctuating currents in the magnet coil, which would travel over the line and set the further diaphragm to vibrating and so reproduce the sounds.

There is no doubt that the scheme would have worked. But the boys fell into the same fatal error which has robbed so many

inventors of a fortune. They failed to complete their experiments. It was summer and there were more important things to be done than staying indoors inventing an absurd device which the world did not want. They decided to go hunting for geological specimens instead. When fall came and the telephone could have been tried again, William was off to medical school and Elihu had his hands full becoming an instructor of chemistry.

How consistently this pattern runs through the long weave of scientific progress, especially with the simple but elusive telephone! Thomas Edison devised a speaking telegraph before Bell but dropped it in favor of more pressing work. There is—or was—a statue to Philipp Reis in Frankfurt which calls him the inventor of the telephone. But it was not Reis who made the fortune or the fame. And there was Elisha Gray, who actually filed a caveat describing the invention at the Patent Office the same day that Bell's application reached the commissioner's desk. But a caveat was only a preliminary notice, not a formal demand for a patent, and so Gray's later attempts to prove priority failed.

Bell received the reward—and deserved it—because he alone saw the value of his invention and kept on till the work was done.

4

In the summer of 1872 Elihu made his first trip away from home, going with Greene for a rowing trip on the Adirondack lakes. Not since childhood had he been so close to nature "in her untouched, unsullied aspect," as he warmly expressed it. Those months in the wilderness refreshed and fortified him for the intense mental activities to come; they gave him a new perspective, a deep and abiding satisfaction in the quiet forests, the great sweep of the mountains, the birds and the flowers with their songs and fragrance. Never again would he be content to do his work exclusively in the laboratory. All his life he would go back to the lakes and woods every summer, not to rest but to renew the bond with nature which he felt so essential to his value as a scientist. Whether in the flash of an electric spark or in the darting silver of a trout, nature's forces were the same in origin and purpose. To understand the pattern of the second was to make the first intelligible. He was no maudlin sentimentalist but a genuine admirer of creation who was inspired by life wherever he found it.

The expedition was taken in the face of poverty. Elihu was so poor that he could not afford the rough clothes that camping required. So he bought corduroy cloth and made them, using a business suit for a pattern. He turned out to be as good a tailor as he was an optician, for the suit wore so long that he finally gave it away to a man who wore it for seven years.

Greene had a rifle of his own and borrowed an ancient Colt for Elihu. There was no ammunition for this shooting-iron; it had long been obsolete. But Elihu remembered from Civil War days how cartridges were made and, after studying the breech mechanism, decided he could manufacture his own. For weeks before the trip he sat over his foot lathe every night cutting shell blanks out of brass tubing. "I also melted and cast leaden bars," he says, "which I turned up into bullets in the lathe to fit the cartridge shells. The real problem, however, was to cause the snapping of the fulminate cap to fire the cartridge through the small opening at the back of the brass shell. I solved it in a curious and, so far as I know, original way. There were to be found on sale small paper caps with a bit of fulminate in them, for use in toy pistols. I pushed one of these caps into the base of each shell, followed it with a charge of powder and pressed the bullet down on top. The firing of the percussion cap by the rifle's hammer sent a jet of hot gas to the back of the cartridge, which in turn fired the paper cap and set off the powder. Thus the old gun became an effective rifle. I had more bullets than cartridges and it was easy to reload the shells and use them over and over again."

The Adirondack outing was one continuous delight of communing with nature and catching fish. The boys did not kill anything larger than squirrels with their rifles since it was the closed season for hunting. But they slew a great many mosquitoes and finally took up pipe smoking when Greene's face swelled up like an Edam cheese from the incessant bites. Elihu had turned out to be one of those annoying campers who do not taste good to insects. However, he loyally smoked during the whole trip to help Greene out. "I did not," he says a trifle sententiously, "continue the use of the weed after we came out of the woods. I formed no habit."

Elihu Thomson returned to work that fall with even more enthusiasm than before. In a short time he was promoted to the post of Assistant Professor of Chemistry and became a regular

lecturer in that department. His students adored him. Though he was almost the same age as some who sat under him, he held his listeners completely, telling them about electricity, which he said would eventually revolutionize lighting and heating and give motive power to machinery.

At this time he became assistant also to Professor Houston in natural philosophy; it was one more small nail in the coffin of their friendly relations. Houston himself was popular—a man with a ready tongue and a genuine flair for epigrammatic phrasing which made his classes always lively. He was something of an actor too, glib and amusing, with the actor's charming freedom from logic. Thomson, being the opposite in every particular, found it difficult to take the professor's classes when he was absent; for there was always the danger afterward that Houston would feel that his thunder had been stolen. For this reason he leaned over backward to maintain the appearance of complete cooperation—even in his own mind.

Honors were beginning to come regularly now. No sooner had "young Mr. Thomson" been elevated on the school faculty than he was invited to become a member of the Franklin Institute. Immediately the High School answered by awarding him a Master of Arts degree and appointing him full Professor of Chemistry and Mechanics. Then came the greatest scientific honor within the power of Philadelphia to bestow. He was made a member of the venerable American Philosophical Society.

There was no recognition in his life that he treasured more than this. In that meeting place in Independence Square, Benjamin Franklin and Thomas Jefferson had brought the society to order as its first and third presidents. David Rittenhouse, Robert Fulton, Samuel F. B. Morse, and John Ericsson had all sat in meetings there. Two British surveyors, Charles Mason and Jeremiah Dixon, had been elected to membership at the time when they were running the Pennsylvania boundary which was to become famous as a symbol of American freedom. And now young Elihu Thomson was to join that celebrated roster, potentially equal to the best of them.

For the next sixty years he made any sacrifice necessary to attend the society's meetings.

Early in his twenties the young man had attained his place in the American scientific world.

Chapter 6

I

Professor Thomson's first duty as a member of the Franklin Institute was to serve as a judge of awards at the society's Industrial Exhibition, commemorating its fiftieth birthday in 1874. This was in itself a considerable honor. He could not understand why his elders had given him such a responsibility so soon. Nor could they; all they knew was that here was a young man in whom one instantly felt confidence. However intricate the duty assigned him, it would not go wrong in his hands.

The exhibition was held in the vast empty sheds of the old Pennsylvania Railroad station at Thirteenth and Market Streets and afforded an interesting contrast between the old Philadelphia and the new. Outside the exhibit horse-cars still rattled along; mules still dragged loaded freight cars through the streets. Inside was a new world just being born—the world of machines—curiosities yet, many of them, but nevertheless unmistakable signs of what was to come.

Thomson was responsible for awarding institute prizes for all electrical and philosophical instruments. This meant that he must have a comprehensive knowledge of everything in that line that had come into use and in addition be competent to decide on the merits of design. The instruments exhibited were mostly telegraphic measuring devices such as the reflecting galvanometer and Wheatstone bridge. There was no dynamo, no electric light, no suggestion whatever of the electrical revolution which was soon to begin. Ten years later the institute exhibited again. This time the entire display was devoted to electric machinery. Elihu Thomson had now become one of the foremost authorities in the field. His lectures demonstrating his inventions quite "stole the show."

The fall of 1875 was memorable for the young professor. During October and November the *Scientific American* magazine pub-

lished several articles on Edison's controversial "etheric force." Thomson read them and finally became so incensed at what he considered unscientific nonsense that he began a series of experiments which eventually drove Edison from the field and wrote an early chapter in wireless telegraphy.

A short reference to earlier history will make the controversy clear. Joseph Henry's experiments in electromagnetic induction, begun in 1832, had established the fact that an unknown form of electric energy could be transmitted through space for short distances. Henry was well aware that this amounted to instantaneous communication without wires. But he believed that it had no practical value. Telegraphy with wires, which he had also accomplished, gave no promise of commercial usefulness, and so naturally a wireless system failed to impress him.

For nearly forty years the scientific world continued to ignore the possibilities of signaling through space. Maxwell, enlarging upon Faraday's concept of electromagnetic waves, showed mathematically that "etheric" communication would be possible if practical sending and receiving apparatus could be devised. But up to 1875 no one took the matter seriously.

In 1871, eighteen-year-old Elihu Thomson suddenly came upon the first element of the solution in experiments with Professor Houston at the Central High School. But he, too, failed to realize their practical significance.

Thomson had been diligently at work in his basement laboratory building various forms of apparatus to demonstrate "static" electricity to his classes. Among these were a huge battery of Leyden jars, kept in a box which the students affectionately termed "the coffin," and a large induction coil which would throw a spark 6 inches through the air. This last, the so-called Ruhmkorff coil, was the descendant of the early Faraday and Henry experiments and was to be found in every school and college science cabinet of the period. It gave a continuous shower of noisy sparks when connected to a voltaic battery and was much favored for demonstrations though it had no practical value.

Thomson had been using the Leyden jars as a condenser across the spark gap of the coil and he and Houston had been speculating as to why the jars shortened and fattened the sparks and turned them a vivid blue. The action of the condenser in

storing electricity and discharging it as oscillations of high frequency was just beginning to be understood.

One day Elihu disconnected the "coffin" from the spark coil and substituted a water pipe and metallic table top as the condenser plates. As he had expected the effect on the spark was the same as with the Leyden jars. But now he made a startling discovery. When the Ruhmkorff coil was running, electric sparks seemed to be everywhere in the room. He found that he could draw them with a knife blade from the table top, from water pipes across the room—in fact, from the frame of a steam engine fully 30 feet away from the coil. He could even light a gas burner by touching it with his knife.

Here was the practical apparatus for demonstrating Maxwell's electromagnetic theory of wave propagation. Indeed, here was wireless signaling actually going on at the Central High School in 1871. But Thomson was too inexperienced to realize what he had found. Nor did Houston appreciate the discovery himself. In the paper which he wrote up on the experiments (and in which he took sole credit for the observations) he recorded what Thomson had seen without comment or analysis. When it was published by the Franklin Institute it passed into oblivion without making the slightest stir.

During the fall of 1875 Edison, experimenting with a large electromagnet, came upon the same mysterious little sparks, jumping between metallic objects around the room. It being his habit never to leave a mystery unsolved, he dropped what he was doing and plunged into a series of tests on the new phenomenon. But Edison was not a trained scientific investigator. Often he jumped at conclusions on the strength of experiments that were superficially right but did not go deep enough. He did so now. When he found that the sparks induced by his electromagnet did not have any effect upon a gold-leaf electroscope, he assumed at once that they were not electrical in nature. He rushed into print immediately, claiming to have discovered a new "etheric force."

"The phenomena observed," he wrote, "attests new principles until now buried in the depths of human ignorance."

The statement annoyed Elihu Thomson exceedingly. Already knowing that a spark discharge was an alternating current which could not possibly influence an electroscope, he saw that Edison

had been fooled. His proof of the supposed etheric force was no proof at all. Such a force could not exist except as a complete denial of the theories of Faraday and Maxwell. So he went to Houston with the *Scientific American* article and proposed that they jump into the controversy.

"It is the same electrical effect that we discovered four years ago," he insisted. "I want to repeat those experiments and prove that Mr. Edison is wrong."

Houston readily agreed. "If Thomson is right," he said to himself, "there will be considerable advantage to us in stirring up an argument."

2

Thomson was already at work setting up apparatus for the experiment. He was quite certain that the so-called "etheric force" was a train of electromagnetic waves sent through space by the rapidly oscillating sparks from the induction coil, an action analogous to sound waves set in motion by the vibrating cords of the human voice. The energy, he believed, was supplied by the coil, transformed at the surface of the condenser plates into electromagnetic waves which traveled out in all directions, and, upon passing through a "receiver" composed of metallic objects almost touching, transformed back again into minute electric sparks. If he was right, the experiments would be valuable laboratory proof of Maxwell's theory, so far existing only on paper. Thomson was, in fact, after bigger game than Edison. He hoped to make a basic contribution to physical science.

Edwin Houston lent little to the occasion except the table top in his ground-floor classroom, where Thomson had set up a large Ruhmkorff induction coil. But Elihu was too sure of his procedure to need his superior's help. The connections were very simple. One terminal of the coil he fastened to a water pipe, the other to a large tin still mounted on a glass jar near by. The coil was supplied with current from a powerful battery of bichromate cells under the table. Any modern schoolboy will recognize that he had made the classical setup for a transmitter of wireless signals.

For a receiver Thomson rigged up a black box, open at one side and provided with two graphite pencil points nearly touching within. One of the pencils carried a large brass knob outside to

absorb more of the waves. Again, the rudimentary radio receiver. From our twentieth century knowledge of electrophysics it seems certain that Elihu Thomson, with the basic apparatus in his hands, must have gone on to discover the whole great principle of wireless signaling forthwith. But he did not. For the second time in four years he missed the practical implications fairly staring him in the face and stuck to his theoretical investigation.

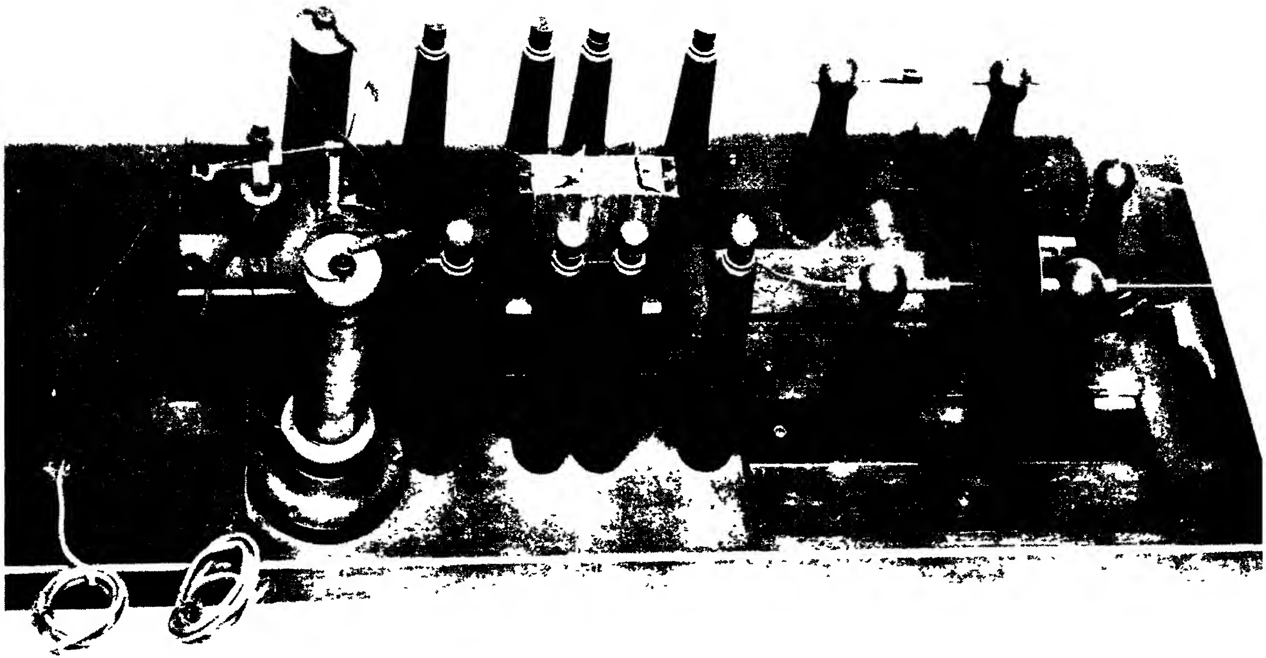
Thomson, the pure scientist, was to the fore that day. He was only the first of that long line of laboratory men—Hertz, Crookes, Helmholtz, Lodge and many more—who must complete their work before the youthful Marconi would see the enormous practical value of electromagnetic telegraphy and at last make it work.

A great invention is a notorious insult to the men who make it. Though a thousand minds labor, it refuses to be born till it pleases and then it turns to mock them all for their stupidity.

No doubt if some prophetic person had told Thomson just then that he had the secret of a priceless system of communication in his grasp, he would have been unmoved. All that he wanted to do was to refute Edison's idea of an "etheric force" and establish experimental proof of Maxwell's waves. Turning on the Ruhmkorff coil and setting the gap to give the brightest and fattest sparks, he began a systematic search for the electromagnetic waves he hoped to find. Everywhere in Houston's classroom sparks flashed brilliantly in the black box. Thomson took it into the next room; the sparks were just as strong. Down cellar they were as good, even to the farthest corner. He found that it was unnecessary to use the box at all. There was runaway energy enough to produce the sparks by holding a sharp pencil against the brass knobs of the doors.

Elihu hurried from room to room, trying every metallic object that was insulated from ground. On the second floor he got the same results, and on the third. Finally climbing five flights of stairs to the observatory on the roof he made the pencil test again and found the wave energy still abundant.

Astronomy Professor Snyder, working quietly in his observatory, was considerably surprised when his visitor burst in. But as the young chemistry instructor panted out an explanation of his experiment Snyder dropped what he was doing and took a decided



Model of the historic tuned-circuit apparatus Thomson used to disprove the Edison "etheric

interest. With growing attention he watched as Thomson drew sparks, first from the doorknob, then from the eyepiece of the telescope, and finally even from a group of small metallic objects in a glass case.

Thomson invited him to try the pencil for himself. Snyder did so, growing more excited every minute. At a time like this the most sedate scientist acts like a child with a shiny new toy. The professor of astronomy knew Maxwell's work well—knew too that he had predicted the passage of electromagnetic waves through space or "ether" between the atoms of all known substances. This was certainly the proof. The spark coil was operating 90 feet below them, and the energy was coming up through five floors loaded with mortar and bricks and heavy beams.

They moved along the hallway to the door of the library, which had a particularly splendid brass knob. Here the sparks were so intense as almost to be audible. Thomson stopped suddenly and grinned inquiringly at Snyder. The older man nodded. "There's no doubt about it," he said. "Electric energy transmitted through space!"

But science is never spectacular all the time. Other very different tests were necessary. If the sparks really were generated by electromagnetic waves instead of by some unexplained "etheric force," they would be absent when the waves were absent, even though the induction coil was still in operation. Thomson devised an ingenious apparatus to suppress the waves without stopping the coil. It consisted of two "resonators" or tuned circuits, each sending out a wave of its own. The two could be adjusted so that their waves would add up and go out together, or so that they would oppose and neutralize each other.

This principle of "interference" was a very old one in the field of light waves, having been discovered centuries before by Newton. Elihu Thomson reasoned that if Maxwell were right in saying that light and electromagnetic waves were of the same nature, then the interference principle should work now.

He was delighted to find that it did work. The two resonators could be adjusted "in phase" to send out powerful waves, giving their sparks all over the building. Or they could be set in opposition, so that no waves went out at all, and consequently no sparks appeared. The induction coil was operating steadily all the while.

Thus Edison's "etheric force" had been shown unnecessary to explain the facts.

But Thomson had done more than refute Edison. Not only was this the pioneer use of tuned electric circuits on which radio would come to depend, but it was also the definite demonstration of the truth of the electromagnetic theory.

Houston now sat down to write the matter up. The paper, as usual, was presented to the Franklin Institute, and signed by him alone. This time Thomson's name appeared once in an inside paragraph. "Immediately on reading the first published account of Mr. Edison's experiments," wrote Professor Houston, "I repeated my original experiments in connection with my friend, Professor Elihu Thomson of Philadelphia." The rest of the paper was sprinked with "I's" so that the reader was bound to get the impression that Houston alone had done the work.

Subsequent generations of readers did get this impression, for Houston's name is sometimes mentioned independently of Thomson's in historical accounts of the wireless art. It is high time that the record be set straight. The discovery was made almost wholly by Elihu Thomson, with Houston only looking on, and later making the report.

Houston's paper, published on December 11, 1875, was reprinted in the *Scientific American* and elsewhere, and both he and Thomson did much further writing on the subject. Some of Edison's engineers took exception to their claims and the expected controversy ensued. But it did not last long, for the "etheric force" could not stand out against positive corroboration of the electromagnetic theory. Edison himself soon lost interest. He was in the midst of inventing the phonograph—a contribution so important that the "etheric force" and his connection with it were soon forgotten.

Many years later Edison sought a share of the credit for basic wireless developments because he had signaled to a moving train from a wire running along the roadbed. The claim was not sustained in court. Edison had only used the principle of induction that Joseph Henry had discovered in 1832.

From 1875 on there were to be frequent controversies between Edison and Thomson, until, upon the merging of the two companies which they started, Edison would surrender the title of

presiding genius to the electrical industry to his friend. There was never any bitterness between them; when they disagreed it was usually because Edison had not gone deeply enough into scientific theory. Often his ideas prevailed for a time, only to succumb to Thomson's superior knowledge in the end.

Elihu Thomson never regretted his failure to be the father of wireless. In later years he said frankly that in those experiments of 1875 he had fully realized that he had discovered the germ of a new system of communication, but he had not been wise enough to exploit it. There were more immediate problems than wireless to be solved.

But this does not detract from the historical importance of his experiments, which have since received full credit for their pioneer character.

The Central High School today proudly cherishes the memory of that moment when Snyder and Thomson bent over the brass knob of the library door and received the first electric "signals" ever transmitted through space. The building still stands and is still in use, the door included. A few years ago Henry Ford sent an emissary to Philadelphia to buy the door for his Dearborn museum, to be placed side by side with Edison's incandescent lamp and other Americana. But the loyal school committee would not sell. It was a good door and still did stout service in a useful room. And the legend on its brass plate drew many a visitor every year.

The legend says:

Benjamin Franklin High School*
Birthplace of Wireless
In this building in 1875
Elihu Thomson and Edwin Houston
Young Science Teachers,
Sent and Received Wireless Waves
To the Distance of 100 Feet.

3

The problem which Professor Thomson thought more important than wireless in 1875 was the invention of a practical dynamo

* The Benjamin Franklin School now occupies the old building where Elihu Thomson worked. Central High has moved to modern quarters elsewhere.

—a machine to generate electric currents by mechanical rather than chemical means.

Although his teaching at the High School was largely in chemistry and physics Thomson was keenly alive to every discovery or invention in the electrical field. Long before the famous "etheric force" experiment he had read of the Gramme dynamo, made commercially practicable in Paris in 1873. A year after this he had actually seen a dynamo for the first time—a crude English machine in a college laboratory. It was being operated by two men by means of cranks and gearing. The current generated was sufficient to heat a strip of metal to bright red—enough, perhaps, to operate a modern electric toaster.

This startling performance left an indelible impression on Thomson's mind. Up to this time he had built "influence machines" for generating static electric sparks, and batteries for steady voltaic currents. But to see electricity actually created out of steel and copper and mechanical energy was a revelation. That one glimpse of the English machine started a whole new train of imaginative thought in his mind—the dynamo was undoubtedly the key to the future. Electricity in any quantity, limited only by the steam power available to make it—what other scientific fact could possibly compare with it in importance? He determined to build a small model dynamo himself.

The iron castings for the field magnets were a problem, but Thomson made up some wooden patterns and got the foundry work done after a fashion by a local concern. Then he tackled the matter of constructing the revolving "armature." He had read much about the Gramme ring armature—a hoop of iron with coils of wire strung around it at intervals. This was claimed to give the greatest efficiency in converting the mechanical power of rotation into electricity. But it was difficult to wind the ring with wire. After he had finished such an armature he designed one of his own, on the principle of a hollow drum with the wire passing over it and around the ends, rather than through the center. This he found much simpler to wind.

The little dynamo was soon finished. It worked beyond his fondest hopes when he belted it up to his foot lathe at home, and especially well with the drum armature. He was elated at this because he supposed the externally wound drum to be his own

invention. Three years later he discovered the whole idea in a British patent granted to the German engineer, Ernst Werner von Siemens. This was Elihu's first experience with treading on the toes of another inventor. He would have many more.

The success of this first small machine led Thomson to build a larger one—large enough to require at least half a horsepower from its driving engine. Buying the heavy castings as before, he did the entire job of machining, assembly, and winding in his Fitzwater Street attic room. This dynamo, too, was a success, working very smoothly when he took it to school and drove it from the small steam engine in the basement.

Not only was the drum construction unknown in America at that time—1876—but the proportions of its coils, as Thomson designed them, were definitely wrong according to the beliefs then current. All other primitive dynamos except the Gramme were using long thin "shuttle" armatures surrounded by equally lengthy magnetic poles. It was contended that high efficiency could be obtained only by reducing the "idle" wire at the ends of the armature coils to the minimum. This wire, since it did not cut through magnetic lines of force, was supposed to be a detriment.

From the first, Thomson thought the idle wire objection a foolish notion resulting from careless thinking. With his usual penetration to the heart of the matter, he decided that it was the passage of a whole coil of wire through the magnetic field that generated current—not merely the horizontal portions of it. Thus the highest efficiency would result from making the coils as compact and short as possible for the number of turns of wire they contained. So he designed his drum short and fat, exactly the opposite from current practice. His machine turned out to be remarkably efficient.

No sooner had Thomson finished his second dynamo than he received the appointment as head of the Chemistry Department at the school, taking the place of Mr. Norris, who resigned. His full life was made even more crowded than before. But he had embarked upon what he believed was the most important work in modern science and was willing to make any personal sacrifice to carry on his researches as well as his regular duties.

As the long hours of concentration stretched further into the nights, his eagerness to pioneer in the new field of the dynamo kept him going. And now a great new element of inspiration came along—precisely at the moment when he most needed it.

This was the gigantic Philadelphia Centennial of 1876.

Chapter 7

I

The United States of America was a century old.

For two years a vast set of exhibition buildings had been under construction in Fairmount Park on the Schuylkill River. Huge sums of money had been collected to build them; the government had lent its enthusiastic aid; every country on earth had been invited to participate. The Centennial was to be the most amazing, the most magnificent display of progress ever attempted by man.

It was to demonstrate that the American nation, so lately a group of scattered pioneers cutting their lonely homes and farms out of a wilderness, had suddenly become integrated. It was to prove that these Americans were now the world's most mechanical people. For in a single century had they not beaten back the wild frontiers to make room for a civilization in which all possible tasks had been taken over by the swift-turning wheels of machines? Was not the future secure—the pursuit of happiness next to complete?

Elihu Thomson was unimpressed by all this fanfare. He saw, as few in Philadelphia did see, that the future was soon to bring an electrical revolution which would make this boast absurd.

To him the great display would be not the symbol of a new age but the epitaph of an old one. To him all the grandeur springing up in Fairmount Park was but an instrument of contrast between the dying age of clumsy machines and the shining new era to come.

But let that contrast speak for itself.

The sky over Philadelphia ballooned with rainclouds hurrying east to be out of the way before the hour of noon. The broad avenues of Fairmount Park were jammed with soggy crowds who had been waiting patiently since early morning. Steadily new

thousands poured through the gates, eager to catch a glimpse of the opening of the great show.

At five minutes to twelve the sun burst through. The tide of steaming humanity rose expectantly against the flanks of Machinery Hall.

Within, President Ulysses S. Grant threw down his cigar and nodded to Dom Pedro, Emperor of Brazil. The two moved forward along their red plush carpet and grasped the starting handles of the world's most gigantic steam engine. The President threw his full weight upon his lever; Dom Pedro did the same. There was a joyous sigh of steam, a retching of the great piston; a groaning of the floor. The 30-ton flywheel slipped around. Grant turned solemnly and shook hands with the Emperor of Brazil.

Outside, bands blared forth from a dozen grandstands; the deafening voice of the government's most powerful foghorn intoned a mighty greeting across the city. With one breath men, women, and children filled the waiting air with a great shout, "Hurrah! Hurrah! Hurrah!"

May 10, 1876; the Philadelphia Centennial was open for business.

In the center of vast Machinery Hall the great bulk of the Corliss engine presided over 14 acres of bedlam—an earsplitting confusion of American inventions which overflowed into a hundred smaller buildings throughout the grounds. There was a "blast engine" which nearly reached the roof, a pile driver set off by dynamite, a clock the size of a grand piano. There were thousands of knitting machines, spinning machines, pumping and cutting and grinding and sawing machines. Here a brace of Gatling guns crowded an exhibit of Indian bows and arrows. There George Washington's musty little carriage stood silently beside the latest brougham in its patent varnish; the two entirely surrounded by gas engines, steam rollers, drill presses, and lathes. There was a brand new "dental engine" for the dentist to work by foot power; there were exhibits of millions of needles and thousands of gold pens; there was a 30-foot tower built entirely of veneer chairs, and a massive glass case of hundreds of blank books, and a statue of Iolanthe carved in butter by a lady in Arkansas, which melted so badly in the daily heat that it had to be hastily remodeled after hours every night.

Hundreds of tons of Russian and German artillery glowered at an American ordnance plant complete with gun barrels and ammunition in the making. There was a new telegraph machine which received and printed weather maps from Washington—the contribution of Joseph Henry of the Smithsonian. There were Edison stock tickers, and brickmaking machines and steam looms that wove pictures of presidents and kings.

A vast organ, bigger than those in Westminster Abbey and St. Paul's combined, faced the visitor entering the main building, and offered him convenient stairways with which to penetrate the heavy mechanisms that made it go. The original "John Bull" locomotive stood proudly on its primitive track outstaring the contemptuous thousands who had been hauled to the Fair on modern railroad trains. Everywhere massive oaken showcases displayed the achievements of a nation just ten years removed from the throes of civil war. Everywhere strange plants and flowers, stranger costumes, and unaccustomed faces sprouted among a chaos of thundering steam hammers and shrieking gears and slapping belts. Everywhere bustles and bonnets, narrow-legged pants and silk hats and canes wove in and out among the mixture of gingerbread architecture and mammoths of glass and steel.

This was the Centennial; this the last word in modern civilization as America had proclaimed it. In its chaotic display of clashing machines, of classic art and callow architecture, ten million people took comfort that summer and went home under the impression that the millennium had come.

But in Professor Thomson's eyes all this was unimportant. The promise of the future was there, but hidden under thousands of tons of spectacular machines. Again and again, from May to November, he visited a small booth in a corner of Machinery Hall, where the French Gramme exhibit struggled for any fragment of attention it could get. So thoroughly ignored was it that the young Parisian in charge had to cry out constantly, "Hilo! Hilo! Venez regarder la lumière électrique! Le transport de force! La galvanoplastie!"

Thomson spent many hours, straining his meager French vocabulary by asking endless questions, many of which the attendant couldn't answer. Most of what he learned he picked up

by observation. A small steam engine stood at one side, belted to a Gramme dynamo. Near by a second machine was running as a motor on current from the first, driving in its turn a little pump which lifted water up into a cistern and produced a perpetual waterfall. Near this again was a tank in which another part of the dynamo current was electroplating objects with silver. And out in front, to attract attention, a tiny electric arc burned with a brilliant flame inside a glass globe.

That was all; yet to the Professor it was tremendously inspiring to know that these things had already been done and to see, at the same time, how very crude and inefficient they were. This was indeed the perfect moment to enter the contest with his own ideas.

There was another dynamo at the Centennial, an American machine made by the Wallace-Farmer Company of Connecticut. But it was more clumsy even than the Gramme and, though quite large, could supply current for only one arc lamp. Sometimes at night this dynamo was connected by a pair of wires to another light outside on the peak of the building, and then the crowds gaped in awe. But few realized what that arc light meant or guessed how soon it would be called the newest wonder of the world.

The Professor often visited another modest exhibit, hidden away in the Education Building and presided over by a bearded young man who was glad to talk to anybody who would listen. This was Bell with his first telephone. He was there against his better judgment and only because his backers insisted on it. The telephone was not six months old then and far from ready for a public appearance. It might have gone home as completely ignored as the dynamo if Dom Pedro of Brazil had not happened on it one day in company with Sir William Thomson, in charge of the jury of electrical awards.

"My God! It talks!" Dom Pedro had cried. Whereupon Sir William had seized the instrument and examined it and had said frankly, "This is the most wonderful thing I have seen in America!"

Elihu Thomson returned from his visits to the Centennial stimulated and happy, his faith in the electrical future confirmed. From that moment on he determined to devote his time to practical inventions in the electric power field.

He was starting work at the very beginning of a new age. Yet the dynamo itself was not new. Faraday's discovery of it was already forty-four years old.

2

When Michael Faraday began his electrical researches in 1831 he gave up an assured income of some £1,000 a year as a professional witness in the English courts. He also resigned his post as consultant to the government, which assured him £500 more. "I have always loved science more than money," he said, "and because my occupation is almost entirely personal I cannot afford to get rich."

That point of view was incomprehensible to his political friends. One of them berated him in his laboratory one day for wasting his time on a small copper disk which Faraday cranked endlessly between the poles of a magnet.

"What possible excuse can you give," said the politician, "for playing with this toy when there is so much work to be done that only you can do?"

The scientist said softly, "Do not be impatient with my toy. Some day you may be able to tax it!"

It was, of course, the ancestor of the dynamo.

The following year the first crude generator of electric currents was invented by Pixii, using Faraday's principle of conductors revolving in a magnetic field. Though improvement was almost imperceptible for three decades thereafter, Faraday lived to see a practical application made. By 1860 a number of dynamo-electric machines were in existence, all using permanent horseshoe magnets with coils of wire wound on a bobbin which revolved past their poles. These primitive dynamos were so inefficient that they were hardly more than curiosities, yet they could be used to supply an "electric flame" or arc between carbon rods.

In the late fifties such a machine was actually installed in the famous old lighthouse at Dungeness. Faraday himself was induced to serve on a consulting board to determine whether the use of these electric aids to navigation should be continued. It was on a tour of inspection on the coast of Scotland that the aged scientist caught the cold which hastened his death.

Neither Faraday nor his colleagues put much faith in the

innovation. Sir William Thomson believed that a chemical battery would "be more economical than any electromagnetic machine." Nevertheless, inventors persisted, and during the sixties half a dozen designs were found promising enough to patent and build. All the prominent European electricians, such as Wheatstone, Varley, Siemens, Pacinotti, and Gramme, competed intensely to reach a commercial goal. In 1866 the Englishman Ladd built an arc lamp and dynamo to light the streets of London. His demonstrations caused a great deal of curiosity but little enthusiasm. The painful glare of the arc could not compete with the gentle glow of the gas lamps of that day.

One serious fault in the early dynamo machines was that they produced alternating current—rapidly reversing impulses generated as the coils revolved past opposite magnetic poles. Siemens and Pacinotti came forward at almost the same moment with a "commutator," or rectifying device fastened on the dynamo shaft, which delivered all the current impulses in the same direction as "direct current." It was an invention of prime importance since it immediately increased the dynamo's serviceability so that it could easily compete with the chemical battery.

Once the commutator principle was adopted, permanent horseshoe magnets were generally abandoned in favor of electromagnets supplied with current by the machine itself. This too was a tremendous advance because it permitted modifications in design to produce dynamos of many different types. They could now be built for low voltage or high, large current or small. And, best of all, they could be made to operate carbon arc lamps with a steady reliable flame hitherto impossible.

By 1870 the basic principles of dynamo-electric machines were everywhere understood. But theoretical knowledge was still so scant that designs were exceedingly clumsy. The efficiency of the machines in turning mechanical power into electricity was no more than a few per cent. Gramme was the first inventor to proportion his machine well enough to justify commercial experiments. Using the unique ring armature, he built several lighting outfits and installed them in Paris, both indoors and out. Their modest success was helped by the French love of dramatic innovations. A few Parisians, at least, were willing to pay exorbitantly for the fun of staring at the blazing electric lamp.

The arc light itself had an uphill fight ahead. It was by nature so brilliant as to be blinding, even dangerous, to look at. It could not be turned down low like the gas flame, but must burn with overwhelming intensity, even in small sizes. The popular scientific axiom of the day was that "the subdivision of the electric light is impossible." In a sense this was true. The total candlepower could be changed by changing the current feeding the arc, but the intrinsic brilliance could not. The high proportion of ultraviolet light (not then understood) could not be altered.

Subdividing the electric light was an experiment which occupied every scientist, but they all failed. Presently it was given up when celebrated men like John Tyndall and Sir William Thomson offered mathematical proof that subdivision was contrary to physical law. The subject became the bête noire of electricity; it was universally agreed that electric lighting had little if any chance to succeed. The fallacy persisted until Edison exploded it with his incandescent lamp.

3

This gloomy situation did not prevent a few inventive men from working on the dynamo–arc-light combination, especially in America. The first of these incorrigible spirits was Professor Moses Farmer of Eliot, Me., whose title had come to him as head of a girl's school. Farmer had already made a name for himself with his model electric train, successfully run by batteries in New England in 1845. He had also invented and installed in Boston the first fire-alarm telegraph system in America and had experimented with electric incandescent lamps with platinum filaments. Forty of them had actually lighted his house for a few hours before burning out.

As an inventor Farmer was tragically unbalanced. He possessed great enterprise and imagination but little scientific capacity. In 1866 he designed and built the first dynamo in America and persuaded a machinist named Wallace to manufacture it in Bridgeport, Conn. A primitive arc lamp went with it, and it was Farmer's hope that he could take the lead in this promising new field. But his dynamo and light were both so inefficient that nobody could afford them. Wallace struggled along with the manufacture in a desultory way for twelve years, never

quite discouraged enough to give up. Farmer, gone broke, went to work for the U.S. Navy as a torpedo expert at Newport, R. I. Finally the Wallace-Farmer system received its deathblow in a series of tests at the Franklin Institute, in which Elihu Thomson showed it to be the poorest of three competing makes.

Quite different is the story of Charles F. Brush of Cleveland, who became the world's real arc-lighting pioneer. He was four years Thomson's senior, but the two were almost identical in their boyhood talent for electricity. Brush had read every scientific treatise available and had made every experiment possible to his limited means. The one thing that had eluded him was the arc light. Finally, at sixteen, he managed to build a set of batteries out of junk and obtain two fragments of carbon, and reproduced Sir Humphry Davy's famous experiment of 1810. The brilliant little light so captivated him that he resolved to go on with the experiments if ever his fortunes made it possible.

Brush was graduated from Michigan University with an engineering degree the same year that Thomson became an "adjunct" in chemistry at the Central High School. For the next few years he was fully occupied, as Thomson was, in earning his living as a chemist. To both young men inventing was a luxury to be paid for by great personal sacrifice. So when Gramme's machine was reported successful in Paris in 1871, Brush had neither time nor means to enter the race. The best he could do was to ponder the problem in spare moments. He saw at once that the dynamo was the key; it was useless to propose an arc-lighting system until a cheap and reliable source of current could be assured. But it was not until the spring of 1876 that he was finally able to build a real machine.

Hindsight makes it difficult to appreciate the obstacles that beset the pioneer in science. The inventions they struggled with are so familiar today that their problems seem childish and their progress stupidly slow. But that is only because we have as a birthright the knowledge which they had to create out of nothing; in their day there was no birthright at all except strength of purpose and faith in the future.

These men rarely had machine tools of their own; the few factories within their reach were too busy with commercial work to fuss with the half-formed ideas of unknown inventors. It was

this situation that forced Elihu Thomson to build all his early inventions at home. It had bedeviled Sir William Thomson when he was developing the siphon recorder and the alcohol-floated magnetic compass. It had plagued young Tom Edison so much that he had built a shop of his own at Newark and later at Menlo Park.

Charles Brush's fortunes were a little better, but still far from ideal. About 1875 he took a job with the Telegraph Supply Company in Cleveland and thus had access, in theory at least, to a good foundry and machine shop. But it was more than a year before he could persuade the shop people to make the castings and parts for the small dynamo he had designed. There was no room for him to try it out at the factory; he had to wait until his summer vacation to make the long-delayed tests on his farm at Wycliffe, Ohio.

At last the day arrived. "It was a memorable one for me," he said in a speech later. "I belted the little dynamo to an old 'horse-power' used for sawing wood, and attached a team of horses. After a little coaxing with a single cell of battery, to give an initial excitation to the field magnets, the machine suddenly 'took hold' on short circuit and nearly stalled the horses. It was an exciting moment, followed by many others of eager experiment. This was my first acquaintance with the dynamo."

The trials were so encouraging that Brush cut short his vacation and hurriedly carted his invention back to the factory. He knew the firm's manager, George Stockley, and went immediately to see him. He told Stockley that he had a dynamo that was a great improvement on anything so far invented. "I want the company to start manufacturing it," he proposed.

"Indeed?" Stockley said. "And what shall I do about the telegraph business? Give it up?"

"Oh no," said Brush. "Continue it until we get started. Eventually it will be a side line. Don't you see the point, Mr. Stockley? Electric lighting is the coming thing . . . ."

The manager did not see the point. The manufacture of telegraph instruments was a gold mine, he pointed out. There was no floor space available for wild experiments. But Brush persisted until he finally coaxed permission to try out his dynamo in a corner of the factory, belted to the shop steam engine.

The young inventor hurried off and built a small arc lamp with an automatic feed for the carbon rods—an invention thought up in the desperation of the moment to impress Stockley. When the dynamo was set up and connected to this he persuaded the manager to come out to the shop and have a look.

Stockley was interested in spite of himself. The lamp which Brush had invented burned steadily, feeding its own carbons automatically without the usual help from outside. The dynamo, though hardly bigger than a toy, carried the load sturdily. But the best of it was Brush's promise that lamps and dynamos could be built for a fraction of what other machines of that date cost.

"Why?" Stockley demanded, cautiously.

"Because," Brush told him, "my designs are better. Because I have studied the problem for a long time. Because, Mr. Stockley, I know the principles of electromagnetism that have to be satisfied."

Stockley said, "Come into the office, Charles, and we will see what can be done."

This was the true beginning of the electric-light industry in America, for the Brush automatic arc lamp and dynamo proved to be just as good as he claimed they were—far ahead of anything else in the field. Out of that conference with Stockley, in the fall of 1876, came an arrangement by which the Telegraph Supply Company was to build Brush dynamos and lights and help him to develop whatever new inventions he might make. The following April the dynamo was patented, and protection for the automatic-feed arc lamp came soon after.

Within three years Brush's prophecy had more than come true. The company had pushed telegraphic instruments to one side. Its name had been changed to the Brush Electric Company and George Stockley was on Brush's payroll as its president.

This young man had succeeded for two reasons: first because he understood electrical principles; second, because his timing had been exactly right. Sixty-seven years after Davy's disclosure of the carbon arc light the world was reluctantly ready for it. As the first practical commercial system in the field, Brush's apparatus had a head start. But he would have fallen by the wayside in the

scramble that soon followed if he had not continually improved his product as he gained experience. After a year's experiment he hit upon the one remaining idea that was needed to change electric lighting from a private venture into a public utility of unlimited scope.

This was the invention of the differential control magnet which kept an arc lamp going steadily without attention but short-circuited it when it broke down and so preserved the path for the current to other lamps. With this it was possible to string a number of lights in series on a single wire looped between the terminals of one dynamo. The economy of the arrangement opened vast possibilities, especially for lighting large halls and city streets. By the end of 1879 Brush was well launched on a standardized system. One dynamo could supply as many as 16 lamps of 4,000 candlepower each, and a 40-light machine was being designed.

The response of the public, however, had been painfully slow. City officials were reluctant to throw away the satisfactory gas light and put in the brilliant arcs. To overcome this inertia Brush cleverly sought out enterprising business people and persuaded them to install the lights as a "come-on" for customers. The first taker was a Dr. Longworth of Cincinnati, who hung a single light from the second-story balcony in front of his office and ran it from a dynamo in the cellar. The advertising value of it was amazing; every night the streets were filled with people gaping at the light and saying that Longworth was a magician.

The Franklin Institute tests of 1878 found the Brush machine to be the best on the market, which gave a considerable boost to Brush's business. John Wanamaker heard of it and immediately contracted with Brush for twenty lights for his new store. A number of smaller merchants in the large cities responded likewise, and in Boston the Mechanics' Fair installed the arc lights in its vast indoor arena. A Boston clothier also bought several and hung one of them over the sidewalk in front of his store. This, in December, 1878, was the first electric light ever to shine in Boston's historic streets.

As the decade came to a close Brush systems began to multiply. Eighty arc lamps appeared in a worsted mill in Providence, R. I. Factories all over New England, finding that electric lights

made night work possible, quickly installed them. New York dry-goods houses bought them. Hotels as far away as San Francisco hung them in their lobbies. City cellars everywhere were filling up with grunting little steam engines and the whine of dynamo commutators. Cases of eyestrain increased amazingly, for people could not help staring directly at the marvelous new light.

But the lighting of streets still lagged. It was apparently not clear how this could be done without endangering the public with the tremendous intensity of the arc. The criterion of the dim gas burner stood in the way. Brush tried to overcome this prejudice by installing a huge cluster of lamps at the top of a steel tower in Cleveland's Monumental Park. It was a mistake. People got the impression that the electric arc was supposed to rival the sun and were more afraid of it than ever.

In June, 1879, Charles Brush at last achieved his goal. In San Francisco the California Electric Light Company opened the first "central station" in the world, selling *electricity* to anyone who would buy it. It was a modest layout to begin with: two small Brush dynamos supplying a total of twenty-two lamps. But the revenue was attractive—$10 per lamp per week. The public did not seem to mind. So many new customers clamored for service that the size of the station had to be tripled in six months. The city itself put up a street-lighting system of twenty tall poles with four lights on each.

A greater triumph followed the next year. The city fathers of Wabash, Ind., decided to light their whole town with a Brush installation. Accordingly a dynamo was bought and placed in the cellar of the courthouse. On top of the dome, four large arcs were raised on poles, high enough to shine into every street and yard. On the night of March 31, before a crowd of ten thousand drawn from near and far, the lights were turned on. "People stood overwhelmed with awe, as if in the presence of the supernatural," said an eyewitness. "The strange, weird light, exceeded in power only by the sun, rendered the square as light as midday. Men fell on their knees, groans were uttered at the sight, and many were dumb with amazement."

Thus the decade of the seventies had introduced the United States to the new art of lighting by electricity. Charles Francis Brush had been the man whose brilliant inventions made this

possible. But Brush was no longer alone. The field was already crowded; others were laying the groundwork for new systems which would eventually rob him of supremacy.

The two foremost contenders, as the eighties began, were Edison and Elihu Thomson. To find how Thomson reached that position takes us back to 1876.

Chapter 8

I

In the fall of that Centennial year the Franklin Institute invited Professor Thomson to give five winter lectures on the broad subject of electricity, "which I somehow had the courage to undertake," he says, "though I was then only twenty-three."

> There was, I was told, some shaking of older heads over the choice of one so young for such a serious task. I really think, looking back, that it was these very doubts that steeled me and filled me with a resolve to do my best.
>
> With apparatus, much of which was new and most of which was constructed by myself [including his second homemade dynamo], I set out to show that electricities of any name, static, dynamic, voltaic, electromagnetic, magneto-electric, thermo, animal, or what-not, were one and the same, not differing essentially in any respect. The textbooks of the day really treated of several separate electricities as if they were distinct varieties almost unrelated.
>
> Not to discover any vacant seats at any of the five lectures was to me a great encouragement.

Rarely in all his long career did Elihu Thomson have to address an empty seat. When he spoke on any subject, professional and layman alike flocked to listen.

The dynamo was an object of great wonder to the audience. He had built a small arc lamp to demonstrate the current, and the brilliant light made a sensation. He also turned the current from a battery into his dynamo and showed how it could be run as a motor. This was another marvel. The whole demonstration seemed like magic. It was magic. This young lecturer was the first anywhere to describe electricity successfully to the public.

Elihu Thomson was like a crusader. His passionate interest in his subject, his broad knowledge of it, his kindness and gentle humor, captivated the large crowds. He made them see that

electricity was not a cold scientific mystery but a matter of growing personal concern to them all. By the end of the winter his lectures were packed.

Rarely does an audience have the privilege of being present at the making of a great discovery. The people who heard Thomson's last lecture had this opportunity, though they did not realize the importance of what they saw. Searching about for a convincing way to show the intensity of the electricities in an induction coil on that last evening, he charged up a Leyden jar with a static machine and then caused its spark to jump through the secondary winding of the coil. This was exactly the reverse of the normal procedure, since this winding was usually used to charge the jar. Thomson himself did not know what would happen; he used a coil of his own making so that, if the windings were burned up, it would be a loss to no one but himself.

What he hoped to demonstrate was a heavy current of low voltage generated in the coil's primary winding when the Leyden jar discharged. To his own amazement he got something more. In preparing the experiment he had fastened wires to the primary terminal and put them lightly in contact to make the expected current visible all over the room. On discharging the Leyden jar a brilliant flash occurred where the connections to the primary were touching. But on repeating the experiment there were no more flashes. Looking down at the wires closely he saw that the current had fused them solidly together. The separate copper strands had welded into one piece.

The Professor did some quick thinking. This was certainly something new—something that should be investigated independently. Welding metals by electricity might prove to be possible at will. If so, it would have important applications. But, obviously, much further experimenting would be necessary before anything could be proved. He decided to say nothing about this for the moment, since the announcement of a new discovery at a public meeting automatically makes it the world's property.

All this passed through Thomson's mind as he replaced the welded wires with others and resumed his experiment with a little remark about "better luck next time." Nobody in the hall knew that anything unusual had happened.

This was the initial discovery of electric welding. The Pro-

fessor would have liked to go on with the experiments and make sure of the theory of it at once. But good judgment told him that the work would be premature. Currents of electricity heavy enough for practical welding were unobtainable. It was more important to continue the work that he had begun on dynamo machines. So he deliberately set aside his discovery till some future time.

It was a wise decision. When he took up welding again eight years later the alternating-current art had come in. With its help the new invention became one of the greatest single contributions to the new electrical age.

Toward the end of 1877 the Franklin Institute decided to buy a dynamo of its own, complete with a steam engine and all the latest apparatus. It would be useful to run an arc light for a stereopticon projector and for demonstrations of electroplating and other electrical phenomena. But the institute was imbued with the thrift of its famous namesake. It would buy no dynamo until it had tested all available makes to see which was the best. So a committee of nine members was appointed to make the investigation. Edwin Houston and Elihu Thomson were high on the list.

The committee believed that a much more valuable work could be done here than simply to find the most economical machine for the institute. Up to this time the importance of dynamo efficiency measurements had not been understood. There was no recognized method of making them. The committee's idea therefore was to develop a standard set of tests and offer them to the electrical profession as the institute's main contribution. This larger objective delighted the society's directors, and they agreed to it at once.

The institute invited several manufacturers in America and Europe to send their dynamos to Philadelphia for the tests, but only two responded, Brush and Wallace-Farmer, each contributing a large and small machine.

However, Professor Harvey W. Wiley of Purdue University—later the famous sane-eating expert—sent on a Gramme dynamo—the very one that had so fascinated Thomson at the Centennial the year before. With five candidates to work with, the committee set about the first electrical machinery tests of all time. Elihu would have liked to contribute his own dynamo too but felt that

it was out of the question. As a member of the committee he couldn't ethically do so.

The tests were highly technical and occupied several months. Briefly, they consisted of belting one dynamo after another to the institute's small steam engine and running each through every possible type of trial, using arc lights for the electrical "load." The committee divided itself into three sections, one keeping track of the power delivered by the steam engine, a second measuring the electrical performance of the dynamos, and a third checking the photometric output of the arcs. The measurement of steam engine power was well understood; so was the calibration of sources of light. But dynamo performance was new ground. Thus there fell on Thomson and Houston the principal original work of the tests.

They were up against serious difficulties in this, for there was no easy way of measuring voltage, current, and resistance at that time. Indicating electric meters were unknown. The only instruments available were a galvanometer and Wheatstone bridge, which first had to be calibrated against a standard resistance and the known voltage of a voltaic cell. It required the greatest ingenuity and patience to devise combinations of these that would give reliable results. At one point Thomson fell back on a home-made calorimeter for measuring dynamo power. The current to be tested was passed through a coil of known resistance, immersed in a carefully weighed volume of water, and the temperature rise was closely determined in a given number of minutes. Calculation of the wattage output was then possible and, from that, an evaluation of the machine's efficiency.

The tests had to be made mostly at night, for both Thomson and Houston taught all day at the school. Many of the runs had to be continued for four or five hours without a stop, in order to get reliable performance information. Thus Elihu rarely got home to bed before two or three in the morning, yet had to be on duty again with his classes at nine. The strain would have ruined an ordinary man, but, like Tom Edison, he seemed to thrive on it. In the intense absorption of creating electrical history he quite forgot to be tired.

The final report of the committee, signed by all the members, was a classic of simplicity and directness. It laid down in clear

detail the procedure for all tests of its kind in the future. The Gramme dynamo, it found, had the highest efficiency, turning 38 per cent of the engine power received into useful electrical work. The Brush machines were close behind, but Professor Farmer's were a poor third, with only 14 per cent. Because the Brush design was the most compact and accessible and the best all-round engineering job, the committee recommended it for purchase by the institute.

The publication of these expert findings had a profound effect on the new arc-lighting industry. Brush became unquestioned leader in the field. The Gramme machine retired to France, and Farmer gave up manufacturing altogether.

But a much more important outcome of the tests than commercial comparisons was the basic discovery that the prevalent theory of dynamo windings was inadequate. Inventors had all followed the old rule of the chemical battery, that the internal cell resistance must be equal to the outside circuit resistance to produce the greatest battery output. Elihu Thomson had demonstrated that this did not apply to dynamo-electric machines. For best performance the internal resistance should be as low as possible, to cut down loss in heat. Once it was made so, the efficiency would rise sharply.

The Professor had found great satisfaction in the hard work of these tests. He had become a leading authority in the new field and was clearly a power to be reckoned with in the coming contest of design. And, as a whimsical sidelight, he had made a very good friend of Brush, who had spent considerable time at Philadelphia during the tests.

2

If Professor Thomson had required any further impetus to push him away from chemistry and into the electrical field, he got it in the summer of 1878. Paris was to hold a grand exhibition of the mechanical arts. For all the excellent work already done by Brush and others, the French were still far ahead in the actual use of electric light. The young inventor resolved to cross the ocean to see what he could learn in Europe.

The trip was a great adventure—a brand new kind of excitement which was vastly refreshing after the years of premature

responsibility. At twenty-five he had already accomplished more than most men at fifty. Surely he deserved a rest.

Elihu's idea of a rest was eagerly to observe everything that came within his reach—scientific, natural, human. Nothing was too trivial for a mental record, and not a record merely but a careful analysis. From morning till night he kept up his search for new impressions in order that he might delve into causes and stock his mind with general knowledge. There was nothing cold-blooded about this. To reach out and absorb the world was as instinctive to him as it is for a cloud to draw water from the sea.

Purposely he made the trip alone, in order to crowd the greatest possible activity into the two short months at his disposal. The crossing by a small steamer was without incident. He harked back with a smile to his earlier passage of the Atlantic in the *Tuscarora*, when all he had wanted was to become a sailor. What a different life it would have been! He was grateful to his father now for having cut that proposition off so short.

Ashore in France the real adventure began at once. Paris! Fabulous Paris, which he had read of so much and seen so often illustrated! Its broad avenues and magnificent buildings; its elegant equipages; its crowds of beautifully dressed people who seemed to have nothing to do but take the air in public—all these were just as they had been in his imagination. Eagerly he plunged in. He had done what he could on the way over with a French dictionary. At least he would not starve.

The exhibition itself was a disappointment. There was little new that he had not already seen at the Centennial. Gramme and Siemens dynamos were exhibited, and a few instruments of interest. But on the whole it was very dull, very showy, and old-fashioned. He found himself being quite pleased at this. Europe had not gone so far, after all. There was much room for improvement without, as he put it, "following blindly in the footsteps of others."

The great showpiece of the exposition was a fine display of electric arc lights running the whole length of l'avenue de l'Opéra and around the place de l'Opéra as well, a full half mile of flooding brilliance. Such an illumination had never been attempted anywhere in the world. The size and wonderment of the crowds seemed

to show that electric lighting had been accepted as the only kind worth having. It had remained for the French to show the world the way.

Thomson, however, was intent upon investigating the machinery which produced all this splendor. He found, as he expected, that it was mostly a stunt. The ornate rows of "Jablochkoff candles" along the avenue were lighted by a battery of Gramme dynamos near by, especially built for the occasion. The current they delivered was of the alternating variety, without commutators, and their efficiency was exceedingly low. The apparatus necessary to keep the arcs lighted up was complicated and expensive and had to be constantly repaired. It was in no sense a commercial installation.

But in the Gare St. Lazare he found an obscure exhibit of eight smaller lights, run by the more reliable direct-current system. These were entirely drowned out by the splendor of the Jablochkoff candles and were ignored by the crowds. But they burned quietly and steadily and were without doubt the most promising forecast of the future in all Paris. Thomson introduced himself to the operators and got a chance to examine the mechanism in detail. He found it entirely familiar—a reliable, old-style construction dating back full twenty years—something he had read about and understood as a child. Suddenly he experienced one of those inexplicable revelations which come at crucial moments to guide inventive minds. Standing there with that comfortably old-fashioned lamp mechanism in his hand he saw what was ahead. "This is my future," he cried to himself. "Lighting by electricity can be improved, and I shall be one of the men to improve it!"

He left Paris exultant, for he had made a decision which would completely change the direction of his life.

To celebrate he made a dash through Europe, crossing into Germany for a look at the castles on the Rhine, then down into Switzerland and so back to England for the passage home. In the Alps his enthusiasm overcame him, for he tried to go mountain climbing on a professional scale. Exactly what happened he carefully omitted to record. "I had one spell of sickness," he wrote to his parents when the adventure was safely behind him, "and that was in Switzerland on the top of a mountain pass in a little inn

where they did not speak English and I was miles from any town or city. I had to get better and I did." Elihu had not been a very good correspondent that summer, even to his mother. The three letters he sent back to Philadelphia were dutiful but dull. With a formality unexpected from so warm a heart he had signed them all "Your loving son, Elihu Thomson." That signing of his last name was a habit he never could get over, even with his most intimate friends.

But when he returned the family could understand. His whole life and interest had focused squarely on the future development of the electric light. Chemistry, optics, physics, all had been pushed aside by the intensely practical urge to make his mark in this new field while it was still new. It would be a mighty race—a race strictly to the swift. For everywhere energetic young men were sprinting hotly toward the goal. To compete in such a race would mean the deliberate abandoning of the school's friendly atmosphere which he loved so well. It would mean struggle, probably poverty, maybe total failure. Yet he must embark upon it. His call had come and he must obey.

3

At once he hunted up Houston and told him of his decision to begin work on a lighting system of his own. "Between us," he argued, "I know we can beat them all!" Whatever Houston's shortcomings, Thomson was fond of him and needed his help. The older man understood electrical theory and had as keen an interest in it as Thomson himself. Besides, two could make their way in this field faster than one. Even mere discussion of the problems was sure to develop new ideas. Edwin Houston had nothing to lose, and so the agreement was soon made: they should work hard together to invent an arc-lighting system that could be put on the market in competition with Brush and the others. Whatever patents might be obtained, whatever profits, should be shared equally between them.

It was an arrangement that Professor Thomson regretted ever after, but at the beginning he had had no experience with inventing as a profession. He did not know how impossible it is to share the child of one's brain and to give credit convincingly to a man who does not deserve it.

At the outset Professor Houston was cooperative enough. The two sat down at every opportunity and discussed the electric light. The talk resulted almost immediately in a good basic idea: the use of an induction coil or "transformer" interposed between the dynamo and each light it supplied, thus securing independent operation of the lights at any voltage desired. This meant alternating current, but Thomson had always favored it. The dynamo was fundamentally an alternating-current machine; direct current was obtained from it only at the expense of a troublesome commutating device. If transformers of high efficiency could be designed, the flexibility of arc-lighting systems could be greatly improved.

The idea held the germ of future electric power systems and was far more important than the two professors knew. At the time, Thomson conceived it merely as a means to escape existing difficulties, a simple first step toward a workable system. He hurriedly made sketches and diagrams and in October, 1879, filed, jointly with Houston, his first important patent.

As he thought over the transformer idea, however, it seemed more and more to offer a new solution to the whole problem. By late fall he was sure that they had hit upon a great thing. Without a moment's delay he designed a new dynamo without a commutator, using two independent coils on the revolving armature to give two separate alternating currents. Getting the castings made for him as before, he assembled and wound the machine himself and before the year was ended had it running.

In the rush of getting the dynamo built Thomson ignored the annoying fact that Houston could not help him in the least. He was utterly clumsy with tools, and after his one attempt at building a model Thomson begged him to leave the shopwork entirely alone. Houston was more than willing to comply.

The dynamo done, the young inventor turned to the making of the transformers. These were merely two windings of wire on an iron core, and he made four of them in order to try out all sorts of connections. As he built them he realized that a slavish adherence to the old induction-coil idea was a mistake; instead of simple iron cores he would *complete the magnetic circuit* as well as the electric circuit by surrounding the wire entirely with iron. Here was another invention of top-rank importance—the

"shell type" transformer, later a keystone in the electric power system.

Ideas were coming so fast that it was difficult to keep them separate. The next was more important still. Why, he asked himself one day, should all these transformers be strung out in series in the conventional way? Why not put them in parallel *across* the circuit and so make them entirely independent of each other? By so doing they could be made very different from one another, even to supplying different kinds of loads. Would this not be at last the true "subdivision of the electric light" which the scientists still said was impossible? He fully realized that it would—and in that moment anticipated Edison's similar reasoning by fully a year's time.

It was only the work of a few hours to draw up a patent specification covering the multiple-circuit idea. But having drawn it, Elihu Thomson hesitated. Why should this patent be obtained jointly with Houston? The older man had had nothing to do with the multiple-circuit idea at all. It was solely Thomson's own conception. The Professor's sense of justice came to his own defense—one of the rare occasions in his life when he allowed it to do so. He resolved to hold the transformer patent back. The specification went into a desk drawer to await a better time.

The delay had a most important effect upon the whole future of the electrical industry. When the patent was finally filed in 1885 it was contested by the examiners and was not granted till 1902. By that time the application of transformers was universal and the royalties due Thomson enormous. But the court disallowed them all. It failed to honor the inventor for his original delay.

Professor Thomson's statement to the court, if not convincing legally, at least made his position clear:

"I believed the (transformer) idea was a valuable one in which my colleague had no part. I was in fact beginning to consider that mere mutual aid and sympathy were not sufficient of themselves to constitute joint invention; especially where a radical departure had been made by one of us, as in this case." He was quite clear in his mind even in 1878 that the arrangement with Houston was a mistake, but he did not see any way to terminate it then.

An earlier instance of the injustice of unequal collaboration had occurred in 1877. While lecturing to a class in mechanics, Thomson had been demonstrating the action of centrifugal force by swinging a vessel of water around his head on a string. Suddenly it had occurred to him that

> . . . no adequate use of the principle had so far been made in the separation of substances of different densities. To test out these matters, I devised a "centrifuge" or "swinging basket"—a device now found in physiological laboratories everywhere.
>
> Following these trials, at which Professor Houston was present, came the continuous centrifugal separator for milk and cream. Taken out as a joint invention on the principle of mutual aid and sympathy, it became the fundamental patent on centrifugal creamers and both of us eventually received several thousand dollars royalty. I never grudged Houston his share, but in reality his part in the matter was very small compared with mine. The original idea was mine and the experiments were financed by my friend, Mr. Henry G. Morris, who, I am glad to say, was far more than reimbursed for his generous outlay.

The cream separator, like most basic inventions, got itself quickly involved in many interesting ramifications. Morris had Thomson make up a model which was run with great success at a Philadelphia sugar refinery. At the trials a Mr. McCollin, a photographer, happened to be present. He asked Thomson if the separator might not be used to concentrate liquid emulsions. Thomson thought it could and gave McCollin permission to try. There were two results. The separator got its start as a laboratory device, and McCollin's friendship presently gave Thomson his start in the commercial world.

The aftermath of the centrifugal affair was a court action which stripped the professors of all further royalties. The original patents had been turned over to the De Laval Company. When business began to prosper this company went into court against various small competitors who had sprung up. Just as the suit was about to be decided in De Laval's favor the defendants brought in evidence that a French inventor had antedated Thomson by fully two years. This man could not be produced

in court because a flying fragment of his centrifugal machine had penetrated his heart and killed him.

When verification of the cause of death was presented the court decided in favor of the defendants. The fact of the flying fragment proved that the Frenchman had indeed discovered the centrifugal principle. De Laval lost the case and ceased paying the Thomson-Houston royalties forthwith.

Chapter 9

I

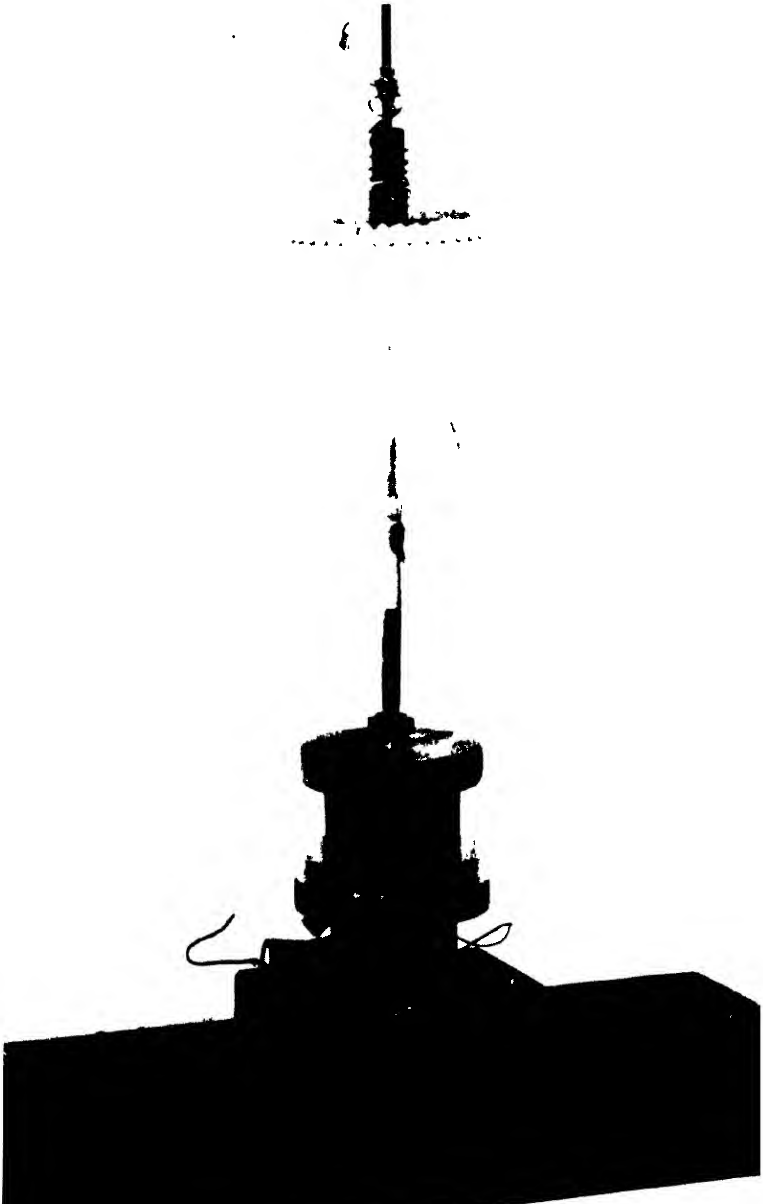
In that winter of 1878–79 Thomson set up his alternating-current dynamo and transformers in the hall of the Franklin Institute and ran them successfully in several demonstrations. To make the system complete he had devised a small vibrating arc lamp, patenting it jointly with Houston. It was a crude little affair, mounted on a board and covered by an ordinary kerosene lamp chimney. But it made history on the institute platform.

Each coil of the dynamo was connected to a transformer, which in turn fed one of the lamps. The combinations were then turned on and off separately, to show how independent they were. It was the Professor's intention to prove the arrangement thoroughly workable and then seek a commercial outlet. But vital moments in a man's career are rarely shaped by the principal actor himself. Quite against his own volition the young inventor was suddenly swept into a channel completely different from the one he had selected. At the last Franklin Institute demonstration his friend McCollin was present, with his cousin, a Mr. Garrett, who was a manufacturer. After the lecture Garrett asked the professor if he thought he could build a dynamo to light four separate arc lamps, as Brush was doing in Cleveland. "A direct-current dynamo," Garrett explained.

"Direct current?" Thomson was disappointed. His whole interest was fixed upon the alternating system. But here was an actual business offer—an invitation to get into the battle of the electric light. The conditions were given; he must abide by them. He must make up his mind on the instant.

"I think I can design what you want," he told Garrett. "Give me till tomorrow morning to study it over."

Talking with Houston next day, an idea suddenly came to him. "I have it!" he cried and ran to the blackboard and made a quick sketch. Garrett's machine would have three coils on its armature



instead of two—three windings symmetrically placed. They would be connected to a three-section commutator on one end of the shaft and to three collector rings on the other. The dynamo would produce direct or alternating current as desired.

Eagerly the Professor sent word to Garrett and McCollin that he could build the machine they had asked for—a dynamo that would be totally different in construction from anything in existence—better, simpler, and more efficient. What a rash young man this was! To startle his backers with a radical departure instead of sticking to the conventional forms which would have been a sounder commercial risk. But this was Thomson. When he saw a better way he adopted it, secure in his faith in his own wisdom. And the businessmen caught this faith from his buoyant message, as other backers would catch it again and again for the next fifty years. They replied at once:

"We will pay the cost of building the first machine. If it succeeds, we will take steps to organize the business."

This wonderful response sent Thomson into a state of intense activity. He was no longer the serious-minded high-school professor, but the blazer of a new trail into the wilderness. He began working like a madman.

"In a day or two, by night work, I had a set of drawings out for patterns and machine parts, and a few days later castings were delivered to Harrison's Machine Shop in Barker Street and work begun." Everybody connected with the enterprise had caught the Professor's enthusiasm. A set of castings for a 5-horsepower dynamo in "a few days" would have been impossible by any latter-day standard.

Harrison's Machine Shop was a modest place indeed, and the coming of the new dynamo was a big feather in its cap. It was composed of two old dwellings connected together; its narrow, low-ceilinged rooms were crammed with archaic lathes and other metalworking tools. A 10-horsepower steam engine furnished the power for everything through a forest of overhead shafting and belts.

W. H. Harrison himself was the same kind of a mechanical pioneer as Charles Williams, the Boston instrument maker who had helped Bell turn his crazy ideas into the telephone. In his rush to get the project going Thomson had omitted to build a

model; all he had was a sheaf of rough sketches. Harrison had never seen a dynamo in his life. He hardly knew what they were. But he did not hesitate when the castings arrived. "You stand around and keep your eye on her," he told Thomson, "and I guess we can get her built."

Build her he did, and in less than a week. But when it came to winding on the wire Harrison was stuck. "There were no men there familiar with such work," the Professor wrote, "and the task of winding this first machine, on which so much depended, was mine personally. In any case I would not have trusted anyone but myself to do it."

That was not strange, for the exact plan for the windings existed only in his own head.

So Thomson did the work himself while Harrison looked on and marveled. Many a gallon of kerosene was consumed in the shop lamps before it was done, for the Professor insisted on teaching all day as usual and so had only the nights to finish his invention.

Early in March the last wire was on and the machine ready for trial. It weighed nearly half a ton and was so large that there was no floor space big enough in Harrison's shop to set it up. Clearing off the bed of a large planer, they hoisted the dynamo up onto it and belted it to shafting overhead. It was unhandy, but at least they would know whether the machine was a dynamo or only a pipe dream that had failed.

The night of the first test Garrett and McCollin, Houston, Harrison, and most of his men gathered round as the steam engine was started and Thomson slipped the driving belt onto the dynamo pulley. The engine groaned for a moment as the shrieking leather wrenched the little machine into motion. Then it took hold, and the dynamo settled down to its run. A grin traveled around the shop. Thomson hastily connected a borrowed arc lamp across the terminals. In the burst of blue light the little shop suddenly leaped into relief in every detail. Cobwebs that had been hidden for years came into view. Dirt and grease, cracks in the wall, piles of rubbish, all stood out painfully clear in the light from Thomson's new dynamo.

"This is most embarrassing," was all that Harrison could think of to say. But nobody noticed. They all knew instinctively that it was a historic moment. And so it was—as important a moment as

that other more celebrated one that would take place seven months later at Menlo Park, N. J., when Edison would begin his forty-hour vigil over the first incandescent lamp.

All night long the Professor bent over his machine, making measurements of speed, voltage, current, temperature, observing every minute detail of the performance more searchingly than he had ever done at the Franklin Institute tests. He was thoroughly happy. Not a detail of his calculations had been in error. The great innovation—the three-part windings and commutator—ran smoothly and carried the load without sparking. This was the best news of all. This "novelty," upon which he and Houston could base a fundamental patent, had proved to be sound engineering.

The next day Thomson invented and started to build an arc-lamp mechanism of his own. This he knew was necessary, since the lighting system must be complete to be salable. In the meantime he pointed out to Garrett that full-load tests of the new dynamo would be impossible at Harrison's, since the little steam engine did not have the power. They must have a larger engine. Garrett proved an admirable backer to have, for he immediately promised to find a Philadelphia storekeeper who would trade the use of his steam engine for the experimental lighting of his place.

By the time Thomson had his lamps built Garrett had found a merchant who was willing to take a chance. The place proved to be Fuller's Bakery on Eighteenth Street. The engine was adequate, but the setting left little to be thankful for. It was a long low-studded room on the ground floor. Two large bread ovens occupied one end of it, with the steam engine near by and mixing machinery scattered everywhere else. The air was moist and pungent and red hot. Houston was inclined to shake his head over the whole affair. It was a pity, he thought, to subject their invention to such an unfair test. But Thomson, busy with putting up the four arc lights and their wiring, waved him aside.

By June, 1879, everything was in readiness, and the test runs began. With a powerful steam engine to drive it, the three-coil dynamo lighted the arc lamps perfectly, flooding the bakery from end to end. Fuller was delighted and wanted to buy the machine at once. But Thomson insisted on continuing the tests all summer. Prolonged use under these severe conditions would "chase the bugs" out of the new dynamo as nothing else could. To do this

he had to face a personal test even harder, for he was determined to be on hand whenever the dynamo was to be run.

> Midsummer in Philadelphia came on, and the actual temperature of the space near the ovens rose at times to 140 degrees Fahrenheit, as I observed by the thermometer. It being vacation time I frequently spent hours during the night in this high temperature, stripped to undershirt and trousers and perspiring at every pore. It was a hard experience, but fortunately there was a "cooler" of ice water and a tin cup handy and I drank very freely indeed of the cool fluid as soon as I began to feel unbearably heated.
>
> Sometimes Mr. McCollin and Professor Houston would call in but they never stayed long. Their chief duty as they saw it was to remonstrate with me for drinking so much ice water. They said it was dangerous to do so when heated. My reply was that I drank before I got overheated and thus kept my temperature within safe limits.

Both gentlemen thought Thomson was crazy and, as if to prove it, both were rather violently ill from heat prostration. At which the Professor was unfeelingly amused. If they had taken his ice-water remedy, he said, they would have been all right. But for once Elihu Thomson's self-medication did not recommend itself to others.

Garrett came in one day to say that he had heard Brush was putting his lights up in series, all on one circuit. Did Professor Thomson think something of the kind could be done with the bakery machine? "Oh, yes, that is easy," said Thomson at once and stopped the dynamo and with a screw driver made a change in terminal connections. In a few minutes he had it running again, lighting the lamps just as Brush lit his. Impressed, Garrett next wondered whether more lights of smaller size could be run from the dynamo. "Certainly," said the Professor, "if we had them I think we could light as many as eight."

Garrett went off and got the lamps and was back in a short time. Thomson had the new connections all made. This professor was an amazing young man, his backer decided. If you asked him for something new he produced it immediately, as if by magic. Garrett said as much. "Not at all," Elihu answered quietly. "I anticipated from the first that this was what we should want.

So I made my windings double, to operate double the number of lights."

Before the night was over they had not eight but nine arcs working perfectly in the blistering heat of the bakery.

The Thomson-Houston electric light system was a success. Garrett and McCollin signed a contract with the two professors immediately, and a small factory was opened in the fall of 1879 at 313 Buttonwood Street. The inventors were to patent the scheme at once and receive royalties on each machine sold. Thomson was to get out all patterns and drawings, train the men to do the winding, and make the necessary tests of the machines. Houston was simply to remain—Houston.

The tough little dynamo in Eighteenth Street was soon famous, and orders began to come in. The inventors now sat down to wrestle with the patent specifications and cover as thoroughly as they could every possible novelty of the system. And here Elihu Thomson had his first lesson in the pitfalls of the Patent Office.

The specifications as he drew them naturally covered the three-coil alternating-current feature thoroughly. But the attorney who was to pilot the application through flatly refused to let this claim stay in. It was the direct-current system they were marketing, he insisted. To complicate it with extra claims would only confuse the examiners and jeopardize the whole patent.

Unwillingly Thomson took the lawyer's advice. Thus he failed to establish authorship of the three-phase alternating-current winding which later became fundamental to electric power systems throughout the world. That it was his own idea is attested by the original little "Bakery Machine," which now holds an honored place in the National Museum in Washington.

No sooner had the patent been applied for than Edwin Houston began to show himself in his true light. Not waiting for the sale of the dynamos, he insisted on collecting advance royalties from Garrett, who paid them rather than make a fuss. Thomson took nothing; he knew that profits were by no means assured. The work of development had hardly begun.

2

The second Thomson-Houston arc-light installation was made in Gardner's Brewery. One night early in 1880 the brewery barns

caught fire and threatened hundreds of valuable horses. But the dynamo and lamps kept on working and by their light all the animals were saved. At the height of the blaze the Fire Chief caught one of his men diligently playing a hose on a sputtering arc.

"What are ye doin', Kelly?" he yelled. "D'ye want us to work in the darrk?"

The fireman quit reluctantly. "What the dickens kind of a light is it, anyway?" he demanded. "Pour water on her and she won't go out."

Even more of a marvel that night was the Thomson dynamo, which continued to operate with many of its lights extinguished. Though half its load was gone, it refused to run wild but adjusted its voltage to the exact amount needed by the lights that remained. That was a feat that even Brush could not duplicate. The worst drawback to all early arc-lighting systems was their inflexibility. They would run a given number of lamps well enough, but if one or more went out the circuit resistance dropped and the unchanging voltage of the dynamo forced abnormal current through the other lamps and blew them up.

Thomson had faced that difficulty during the long torrid nights at Fuller's Bakery and had experimented with regulating devices to vary the dynamo voltage according to its load. The result had been an electromagnetic regulator which automatically shifted the brushes on the commutator to give a constant current, regardless of the resistance of the outside circuit.

This little device soon gave Thomson an advantage over his competitors that kept him in the race till he was commercially on his feet. The regulator, which he immediately patented, provided the only simple means of making the lighting circuits dependable. Without automatic control the operators of Brush and other systems were sure to be in trouble about ten o'clock every night, when their customers began turning off their lights. As the load dropped off the powerhouse attendants would be thrown into a scramble, trying to adjust the voltage by hand, while the machines sparked and ran wild. The only safe way was to hang row upon row of arc lamps in the station itself and as fast as customer's lamps went out to turn these on. Thus as the night advanced the dynamo rooms would be ablaze with wasted light that no customer would buy.

The electrical scene in the spring of 1880 was indeed a battle. Everywhere young inventors were hurrying to machine shops with dynamos of new design, making hasty arrangements to share their patents on any terms they could obtain. Most of them relied upon some alleged improvement that would keep them in the fight until they became commercially strong.

In every locality salesmen were descending upon the retail merchants and city fathers, trying to stampede them into buying one lighting system or another quickly before a competitor arrived. Few indeed of these advance agents knew the first thing about the arc-lighting principle or the comparative merits of their system measured against the others. And meanwhile the Patent Office was deluged by a storm of applications and drowned in a sea of conflicting claims. The Forty-Niners of California had nothing on the inventors of 1880, pushing and crowding for a place on the mother lode.

Charles Brush was still far in the lead, mainly because he had had the good luck to invent the copper-coated arc-light carbon, and the differential magnet. This cut down the resistance of the long carbon rods and concentrated the electric power in the arc itself. Thus his lamps were more efficient than others and attractively economical.

Edison, the "Wizard of Menlo Park," meanwhile was working an unwizardly twenty hours a day completing the invention of the electric incandescent lamp. In October, 1879, he had kept a carbonized cotton thread glowing in a vacuum for forty hours before it failed, and he was now sealing carbon "filaments" in glass globes which would burn a hundred hours or more. It was an achievement which shook the scientific world to its foundations and got headlines in the public prints.

Here was a young American who had at last "subdivided the electric light"—a feat which every expert had said was impossible. Here was a new source of electric illumination that refused to abide by the rules, that could be cut up into as many small units as needed.

For a time the highest authorities on both sides of the Atlantic refused to believe it. Edison was called an impostor. It is hard now to understand the mistaken point of view which made such nonsense plausible. It arose because everyone assumed that it was the arc light which Edison had subdivided.

It was quite true that the arc light was indivisible in the sense that its intrinsic brilliancy could not be reduced. The mistake came in the failure to realize that Edison's incandescent filament was a source of light totally different from the electric flame between carbon rods. The new lamp was simply a thin wire of high resistance raised to a white heat by the passage of current. The arc, on the other hand, produced its light by *consuming* carbon from the tips of two separate rods. There was a fundamental difference in the physics of the two, which denied comparison.

This difference was not guessed in that early day. Some of the wiser heads were in doubt and reserved judgment. But no one was comfortable about it. In England both Sir William Preece and Professor John Tyndall said publicly that subdivision was unlikely. In a lecture before the Royal Institution, Tyndall—the foremost authority of his time on electrical research—said, "Knowing something of the intricacy of the practical problem, I should certainly prefer seeing it in Edison's hands to having it in mine."

Edison himself ignored the whole controversy and was now furiously at work inventing a dynamo of his own and designing a whole new distribution system to go with his incandescent lamp. As everyone in the arc-lighting field well knew, Edison was the most formidable force in electrical science and would soon have to be reckoned with. Everything he had touched so far had turned into a gold mine. Wall Street was ready to back him the instant he produced anything new. He had a large and highly trained organization of his own, capable of carrying out the thousands of separate experiments he deemed necessary to perfect his light. On top of all this he had on his payroll one of the first electrical mathematicians in America—a brilliant young fellow named Francis Upton. Recently "the Chief" had said to Upton, "Frank, soon we shall have a light that will work. Design me a dynamo that will beat them all." And Upton had designed just that—a machine with an efficiency of nearly 90 per cent.

Real engineering was coming to the fore. Upton's great achievement was in avoiding the large stray-current loss in the cast-iron armature of the dynamo. By abandoning castings and using thin sheets of insulated steel bolted together, that loss was reduced to a small fraction, and the dynamo's efficiency greatly increased.

To complete the complicated picture the powerful gas-light

magnates were becoming alarmed at the prospect of competition which they could not combat. They feared that the new "subdivided light," if successful, would be their death knell. Gas company securities on the stock exchanges were beginning to sag; everywhere executives were gathering in lawyers, economists, and orators to prepare a campaign of mass fear, hoping to frighten the public away from the "deadly" electric light.

Thus did the spring of 1880 furnish a scene of mechanical combat so typical of Yankee genius and so dear to the American heart.

Chapter 10

I

Busy as he was during the winter of 1879–80, Professor Thomson followed Edison's work keenly. He did not believe that the incandescent lamp could seriously compete with the arc for large-scale lighting, but he knew that it would be folly to leave the matter to chance. So he made a trip to Menlo Park to see just how things stood.

Ever since the famous "etheric force" controversy the two inventors had known each other through the public prints. Each was curious to see what the other was like. But they did not meet as rivals. Edison was very anxious to make a friend of Thomson, whose knowledge he greatly admired. The Professor was equally anxious to study the high-pressure methods which had made so many of Edison's inventions overnight successes.

Unfortunately, no details of the meeting have been recorded. Edison greeted the Professor cordially and took him at once to the upstairs laboratory where the new light was set up. They spent several hours there, discussing every angle and detail of the device and exploring the future of electric power in general.

When Thomson left, Edison gave him an experimental lamp and asked him to test it and give him an expert opinion on its shortcomings. They parted the best of friends.

The Professor returned to the Central High School with this treasure and caused great excitement by showing it to his classes, drawing the curtains, and setting it alight with current from his own dynamo. The little lamp was a feeble thing indeed beside the arcs which the students had so often admired. Its horseshoe strip of carbonized thread glowed only a mild red on the 100 volts pressure it was designed to use.

Professor Thomson here made one of the few errors of judgment in all his career. He said he did not think very highly of the Edison lamp and expected no great future for it. This was not so much because its light was dim, for it could no doubt be improved to

approximate the intensity of the gas flame, but because it was so inefficient. The future of electric lighting was a commercial proposition entirely—a question of services rendered per dollar of investment in machinery and copper wire. The current consumed by many lamps would necessarily be large. To transmit it over any considerable distance at the low voltage required by the delicate filaments would mean enormous outlays in copper conductors. The arc-light system, on the other hand, required very little copper. Its high-efficiency, low-current circuit could pour thousands of candlepower into public places at small expense.

The gist of these arguments Thomson and many others brought to bear upon Edison forthwith. But the inventor ignored them entirely and pushed ahead with his incandescent system in spite of all the impossibilities that could be hurled at him. His great genius was shown less in his invention of the new lamp than in his determined search for a new principle of electric distribution which would be both practical and economical. After two years of intense thought and experiment he found it and in spite of all the doubters made his triumphant entry into New York City with a lighting system that did not require "all the copper in the world," as prominent engineers had predicted it would.

Edison's greatest contribution to electric lighting was the multiple system of current distribution by means of three feeder wires instead of the conventional two. Inefficient as the lamp itself remained, in comparison with the arc, the enormous advantage of thousands of small lights in offices and homes entirely outran the disadvantage of heavy investment. The world's experts were not wrong, as far as they went; they were simply too conventional. Edison had not done the impossible; he had merely found a solution which sidestepped the theoretical difficulties entirely.

Nevertheless, Elihu Thomson did have the last word in the argument over electric distribution. Before ten years had gone by Edison's low-voltage system had reached its economic limit at a radius of about three miles and was facing a complete impasse. The incandescent lamp threatened to remain forever an expensive luxury, fed by power stations that must be built virtually next door to the customer's premises. Then Thomson did as Edison had done before him—sidestepped the impossible with a solution

wholly new—the invention of high-voltage alternating-current distribution.

But this is a story for another chapter.

2

In the last months of 1879 the Professor noted the threat of the incandescent lamp and put it aside. There were more immediate problems within the arc-lighting field itself. Though fully aware of the intense competition to come, he faced the future confidently, having no doubt that he could invent his way along with the best of them.

Garrett and McCollin were equally courageous. Already they had abandoned the first small factory in Buttonwood Street and had moved into larger quarters on the outskirts of town. Three-coil dynamos and Thomson arc lamps were beginning to come off the testing floor in appreciable numbers, and there was never a moment when they were not sold out in advance. The fame of the Thomson-Houston electric-light system began to be known beyond Philadelphia.

The Professor was so busy that he had no time to be surprised when a prominent lawyer of New Britain, Conn., a Mr. Frederick H. Churchill, appeared in Philadelphia one day and without any ado whatever made him an offer for his services. He said that he was an inventor himself, in a small way, and was convinced that there were vast sums to be made in the electric manufacturing field. Now that factories for making arc lights were springing up everywhere he and his friends in New England had resolved to organize one of their own in New Britain. Would Professor Thomson join them in the enterprise?

Elihu Thomson looked at the lawyer candidly. He was, he explained, under an agreement with Garrett and McCollin and could not leave them.

"Let them come in with us," Churchill countered. "There will be room for everybody. This is going to be a large concern."

Thomson held him off, meanwhile showing him the plant and explaining to him the features of the three-coil dynamo and its unique automatic regulator. If he intended this as a graceful dismissal he had made a sad mistake. In half an hour Churchill had become so enthralled with the Professor's gentle but lucid way of

explaining things that he would not take no for an answer. "I am going home," he cried delightedly, "and tell my associates that you will come!"

Negotiations went forward for several days after that, and at length a tentative agreement was reached. Garrett and McCollin both cooperated to the utmost; they knew their limitations and were quite content to accept Pennsylvania and three neighboring states as their own territory while relinquishing the national field to Thomson and his new friends. Garrett, like everybody else, had fallen under the Professor's spell. "I would not think," he said, "of asking a young man of your talents to remain in Philadelphia. We are too conservative to provide the money for a large experimental venture. There are too many Quakers here. New Britain is your golden opportunity. Take it."

Elihu Thomson did not make his decision without a struggle. The move to New Britain would bring a complete uprooting of his life, the abandoning of everything he had been accustomed to. It would be the end of his teaching career and the loss of intimate friends like Greene, Snyder, Stuart, and the men of the Franklin Institute. It would mean leaving his family behind, probably for good.

On the other hand there were great advantages, not the least of which, he had to admit, was the ending of the bothersome collaboration with Houston. By and large, as long as he had resolved to become a professional inventor, he was better off to take the most vigorous proposition that offered. This certainly seemed to be it. New Britain was a fine town, the headquarters of the famous Stanley hardware business. How could the project fail?

Nevertheless he was not willing to commit himself until he had visited New Britain and tested the enthusiasm of Churchill's associates. Thomson's habit of approaching every new project in its larger aspects gave him a natural business acumen—a rare possession indeed in one who was so able an inventor. He did not intend to change his whole future now until he was satisfied that the gain justified the risks. Churchill cooperated gladly; Professor Thomson's presence in New Britain would make it much easier to sell stock in the new concern.

Thomson also had sound promotion ideas. "In order to assist in securing subscriptions," he recalls, "we proposed to hold an

exhibition in New Britain of our apparatus. There was an unused building called the 'Basket Shop' on Arch Street in that town and this was chosen for the purpose. There was an old engine in the shop with a boiler of rather limited capacity, but we thought that perhaps by careful handling it would suffice."

With Mr. Garrett's approval a ten-light dynamo was hurried through in Philadelphia and sent up to New Britain, where it was belted to the ancient steam engine and started up. Thomson strung the lamps through the rooms of the old shop. "When they were lighted they produced the most brilliant effect in the town, which up to that time was not favored by any such lights." He was quite right in thinking they would attract attention. Many people feared the ramshackle old Basket Shop was on fire. When they rushed there they found themselves ushered into an unbelievable new world.

The grand opening took place on March 29, 1880, which happened to be Thomson's twenty-seventh birthday. He regarded it as an omen of good luck, which in the long run it was.

From the start the new undertaking was immensely helped by his genius for selecting able and loyal assistants. A mechanical virtuoso, for example, was needed to keep steam pressure enough on the patched-up boiler to run the dynamo and still not blow the whole outfit through the roof. For this touchy job Thomson chose Joseph Wright, a young man who had been the engineer at Fuller's Bakery. All that sweltering summer of the tests Joe had watched the inventor and admired him for his patience and good nature under most trying conditions. When Garrett had started making dynamos Wright had begged Thomson to let him come along, and the Professor had made him his shop superintendent and right-hand man. And now he naturally followed him to New Britain.

This was not simply a friendly gesture on Thomson's part. He had sized up his man and believed in him. "Wright had all the needed characteristics to make a success of the project—genial, clear-headed, a fine sense of humor. He got out of that old engine at the Basket Shop all that was in it." And when the boiler ran out of fuel at a crucial moment of the exhibition, Joe ripped up the old basket machinery and burned it without saying a word. He had the flair for taking a chance that was needed for such an experiment as this.

Those were the days when bright young men with mechanical talent could get in at the bottom of a new industry destined to change the world. If they had vision and courage enough to take a chance there was almost no limit to the heights to which they might rise. There were no precedents to break, no long ladder to climb to eventual fame. Actually, they were building the ladder rung by rung as they went, often stepping off into space and reaching back to construct the pathway behind them.

Inventors, mechanics, promoters, all were of equal rank at the start of this new contest with nature. All shared equally in the work; all took the same tremendous gamble with failure and success. All were young, eager, inexperienced, scornful of the manifest impossibility of the thing they were about to do. The future was theirs for what they could make of it. Thomson had not misjudged Joe Wright; in later years he became chief engineer for one of Canada's largest electric utilities.

The Professor left no stone unturned to make the Basket Shop display a real show. Besides the lights, he strung wires to a smaller building across the yard. Here he had belted up a second dynamo as an electric motor, turning a buzz saw which had formerly been run by steam. During the day this was operated as the main exhibit, kept busy sawing up firewood. Anybody who hauled his logs in would have them cut up free by electricity, while listening to Thomson's fascinating explanations, which were in truth the best kind of sales talk in the world.

Quiet little New Britain was fairly shaken out of itself by the Basket Shop demonstration. Investors flocked in; within three weeks Churchill collected the $100,000 capital he needed. Practically every businessman and banker in town had taken stock in the new enterprise, which was organized under the sturdy title of "The American Electric Company."

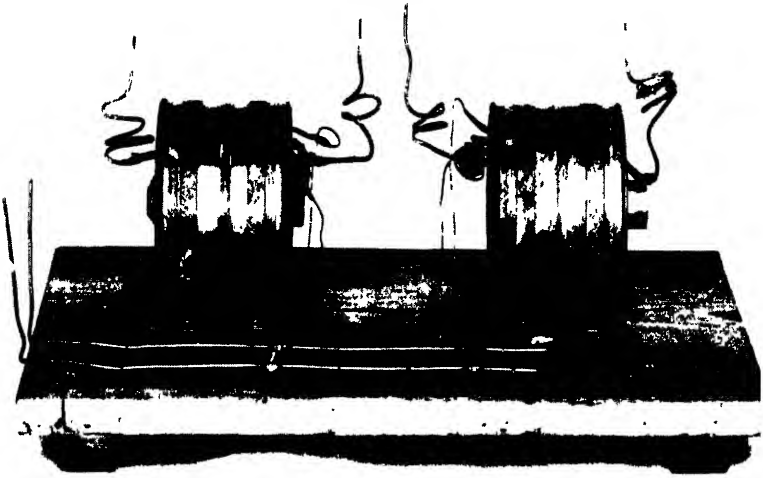
The preliminary sounding out of New Britain had been most successful, and Thomson believed that it would be safe to complete the deal. So early in July he and Houston signed a contract with the new company. Being thoroughly familiar with legal procedure, the Professor demanded and received an eminently fair bargain from his promoters.

The wording of the contract was his own, and every phrase was carefully considered. The American Electric Company was to exist

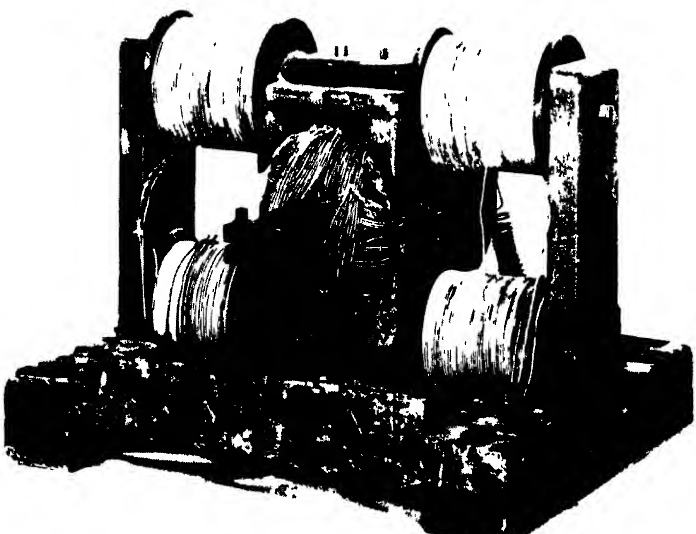
solely for the purpose of exploiting the Thomson and Houston patents. It agreed to develop and manufacture their inventions "with all reasonable diligence." The products were to be sold and put to public use "by diligent and continuous attention, in all reasonable and advisable ways." This was to continue for eight years, and future inventions within that time were to come under the arrangement. For temporary use of the patents the company was to pay the inventors $15,000 each in stock, and a small sum in cash. Professor Thomson, furthermore, was to become "electrician" for the firm at a salary of $3,000 a year, and would be in sole charge of the engineering end of the business. Houston was to be retained as a "consultant," at $750 a year. He was to have no duties and was not expected to come to New Britain at all. "A sort of good will retainer, it was," said Thomson laconically in after years. It might also have been called an inducement for Houston to stay away from the business. For that was, indeed, what everybody connected with it, including Houston, wanted.

This rather modest financial arrangement would have been suicidal if Thomson had not put in a protecting clause at the end of the contract. If, he wrote, the company failed to live up to its duties "with all reasonable diligence," then the inventors could hand in their stock and demand the return of the patents and the dissolution of the business.

By that one stipulation Thomson foresaw trouble that actually came later on and kept both his inventions and his talents from passing out of his own control. Those two or three sentences eventually stood between him and the blockading of his career. It was a clause that few inventors nowadays can hope to get into a contract, however important their patents may be. An invention is usually sold outright, and the inventor himself becomes an employee with no other privilege than the right to quit when he is dissatisfied. This system is a cause for much complaint among minor inventors who have read of the dramatic successes of former days and expect to build great fortunes out of a single gadget. They forget that the pioneers took enormous risks and that they worked happily, day and night, for years, for no other reason than the love of the work itself. They also forget that the smallest invention today requires an enormous further investment of brains and



Model of the earliest multiple-connected lighting transformers



Elihu Thomson's first two-coil dynamo

tools to fit it successfully into the swiftly moving juggernaut of our mechanical civilization.

The great risks and the complete independence of former days have gone. But they have been replaced by security and by scientific opportunity limited only by the inventor himself. The present research men of Thomson's caliber are as happy and productive in their vast industrial laboratories as were their forebears at the dawn of the engineering art.

3

Professor Thomson spent the summer of 1880 winding up his affairs in Philadelphia. It was a sad break for him to make. All his thinking life had been spent in this city so rich in the twin traditions of America and of science. The influence of Benjamin Franklin was strong upon him, with its spirit of inquiry and progress. The Philadelphia he had known for twenty-two years was a city of eager, intelligent people anxious to be informed in chemistry and electricity, willing to turn out in large numbers to hear lectures and witness demonstrations. It was here that he had acquired the knowledge and developed the wisdom that had given him top rank among his contemporaries. It was here that he had learned to impart to others what he knew and in so doing had found the secret of making people love and respect him. It was here in Philadelphia that he had risen to the full intellectual stature of an American pioneer.

What lay ahead in New Britain was in doubt. Certainly the atmosphere of this provincial little town was no match for the thing he was leaving. Though only ten miles from Hartford, it was small and isolated, its people mostly commercial and probably unimaginative as well. There was no Franklin Institute there, nor an American Philosophical Society to surround him with scientists of his own kind. He would be wholly alone.

Elihu Thomson's adventurous spirit bade him go with courage, just as his father had ventured to an unknown America in 1858. But his emotional being clung to the city to which he owed everything. It was like him, then, to face the adjustment squarely and fight the matter out and then drop it completely. He resolved to take the memory of Philadelphia with him and to use it as his intellectual guide. But he would not regret what was lost. Perhaps

he could build something new on the same pattern that would be even better than the old.

His mother more than anyone else helped him to this decision. She would lose most by his going, yet she was so very certain that he must go that she devoted their last days together wholly to making plans. She and the others would be there whenever he could come back for a visit; it was the future he must think of, not the past. For this splendid attitude he was forever grateful. It helped him to put his whole mind on the complicated problems that were ahead.

The Central High School was as sorry to see him go as his family and friends. The faculty held a special meeting on the eve of his departure and smothered him with eulogies and regrets. In return Professor Thomson acknowledged his great debt to the school and expressed his affection for it in a charming compliment. No matter what title he might later win, he said, he would always prefer that of "Professor," which he had earned at the Central High. Teaching was the most satisfying pursuit he could imagine. He would always be yearning to come back to it. He would always look back upon it as the most important influence in his career.

The Professor was better than his word, for he did not leave the teaching profession at all. Throughout his life his relationship to the men who worked for him, and indeed to all who knew him, was that of instructor and pupil, of father and son. Though he became in fact a teacher at the Massachusetts Institute of Technology and finally its president, in the larger sense his professorship to the whole world was what gave him the greatest happiness of all. As an old man he said, with a real sense of fulfillment in his voice, "I believe I have been a teacher all my life."

President Riché of the High School accepted the compliment with grace, and the faculty gathered around "the Professor" with warm personal regard. It was a perfect moment, marred only by Professor Houston, who felt it his peculiar duty to sound a different note. He would like to congratulate his colleague, he said, on attaining a position that would promise greater pecuniary reward.

The room was silenced.

It was a matter of genuine delight to Professor Thomson, however, when Dr. Riché told him that his dear friend Dr. William Greene had been appointed to the chair of chemistry he was leav-

ing. Elihu and William had seen each other constantly all these years, had worked and played and dreamed together, had discussed the future and laughed over the clumsy past. The separation saddened them both deeply. But it was a consolation to know that the new approach to chemistry through experiment, which Thomson had pioneered, would be in sympathetic hands.

Thinking of Greene the Professor realized all at once how very barren New Britain was going to be. It was quite necessary, he felt, to have someone to talk to, to work with, to try his ideas out upon. He cast about for such a person to take along as his assistant. A most fortunate choice presented itself immediately in the person of E. Wilbur Rice, Jr., his star scientific pupil of the past four years.

Young Rice had just graduated and was eighteen years old. A bond of friendship had grown up between him and Thomson, for their minds were much alike and their interests identical. The youth had marked experimental ability; he was eager and earnest and as much a glutton for work as the Professor himself. And, like everyone else, he had fallen under the Thomson spell. His experience so perfectly demonstrates the inspiration which the Professor transmitted over and over again through the years, and upon which so many great inventions were built, that it is worth examining for a moment now.

At Elihu Thomson's eightieth birthday dinner, Dr. Rice, now a top-ranking celebrity in the electrical industry himself, looked back tenderly, thus:

> He has been "my professor" ever since I met him away back in the year 1876 in the Central High School. He was the youthful instructor of chemistry in his twenty-third year and I a young student of fourteen. . . . On my side it was a case of love at first sight, and what a discovery! What a mine of knowledge, ready to be explored, as willing to give as I was to receive its richness. There was no question that I asked to which I failed to obtain a satisfactory reply, expressed in language that I could understand. . . . He explained to me his method of grinding a glass mirror for a telescope. He also taught me how to grind lenses for microscopes and explained the mystery of the rainbow.
>
> The reasons which he gave for the seasonal change in the

> color of a rabbit; for the imitation by certain flies of the honey-bee or of the stinging wasp; for the mimicry of leaves and sticks by butterflies and beetles, appealed to me as much more plausible than the orthodox doctrine . . . that all these things were created for man's enjoyment or for his discipline.

All through his four years at school Rice had literally sat at his Professor's feet and had emulated him in every way he could. Thomson's friendly attitude gave the boy the courage to waylay him at recess and after school to seek his advice. He was building at home everything he could manage to copy from what the Professor himself had built—telephone, batteries, bells, even a replica of the three-coil dynamo itself. And he was as eager to learn principles as practices. It was natural that Thomson had become attached to this boy who said with a grin, "I love the smell of a new book!"

So now, at the end of his Philadelphia days, the older man, himself a youth starting out in a lonely world, turned to the boy who had so often turned to him. Rice had asked the Professor to advise him about his future. Should he go to college or start out in business? Ought he to become a scientist or follow a talent for management which he seemed to possess? Thomson discussed the matter candidly.

"I will offer you a job as my assistant," he said. "The enterprise is novel and of great promise. The opportunities are beyond present measurement. So are the risks and the responsibilities. If you come with me you will work harder than you imagine possible. But you will probably go farther in the end than if you waited for a college degree."

"I will go with you tomorrow," cried Rice. And so began an association that built one of the greatest industrial structures in history.

Chapter II

I

In the fall of 1880 Thomson and his youthful assistant arrived in New Britain determined to make the best of a difficult commercial situation. They were much more afraid of their arc-light competitors than of Edison. Brush now owned formidable patents covering the mechanism of the arc lamp so thoroughly that there seemed no way to avoid infringement. Other forces had appeared on the field with equally important assets: the United States Electric Company with Edward Weston's high-efficiency dynamo, Jimmy Wood's concern with a machine almost as good. All of them were well financed and had a long head start.

To offset these advantages the little American Electric Company had only the automatic current regulator and the inventive talents of Thomson and Rice. Yet the Professor was not downcast. What he proposed to do first was to examine every feature of the competing systems and match them with inventions of his own, not only keeping his place in the field but, by basic improvements, eventually driving them out.

The commercial struggle was a great and thrilling game in these times—a free-for-all as wild and exciting as the pioneer crossing of the plains. The Patent Office granted patents without challenge in most cases. The inventor of a new machine usually entered much more sweeping claims than he could defend and received the government's acquiescence to all of them. Then he prepared to meet the inevitable litigation of his competitors.

A patent in those days was little more than a license to go to court and fight. The government gave no assistance in selecting the claims that were genuinely original but left the burden of proof entirely on the inventor and forced the judge to become the arbiter in many a bitter technical controversy he was not fitted to decide. Nobody liked the arrangement, but at that moment it was unavoidable—the chaotic result of the scramble to get

in on the ground floor of the electrical art. No one stopped to consider then that the situation was heading for a state of deadlock in which no one could legally patent anything at all.

Professor Thomson's encouraging start with the Basket Shop exhibit was not continued in the actual beginnings of the American Electric Company. All that he found on his arrival in New Britain was an exceedingly modest little factory that had been leased from the Stanley hardware people, containing an old boiler and a steam engine of 25 horsepower. The building was a two-story wooden structure about 30 feet long and 16 wide, with a single room on each floor. Downstairs the steam engine took up considerable space; the rest was empty—not a machine of any kind to help the venture get under way.

Thus, instead of going directly to work building dynamos, Thomson had to go out and purchase such lathes and planers and drill presses as his backers were willing to afford. In utmost haste these were installed, with their familiar tangle of belts and pulleys and shafting. To get power upstairs for testing new dynamos, a hole had to be cut in the ceiling and a special arrangement of shafts and belts put in. Here the Professor added a "belt dynamometer" of his own design to measure the power absorbed by the machines under test.

The attitude of the backers was even more disappointing than the quarters they had provided. Apparently they were already afraid of the risks they had taken and planned to "sit tight" and see what happened. The only sales office was in the factory itself—none had been opened in New York or Boston or even in Hartford ten miles away. This put the company under an extra handicap in its struggle against its competitors, who were commercially organized to the limit. Nevertheless, Thomson accepted the shortcomings as he found them. He did not stop to argue or make trouble but took the extra burdens in his stride. Time was short; none could be wasted in making others do their jobs; it was better to do them himself, along with his own.

Late that fall American Electric dynamos began to be built and tested and sold. Better still, the "experimental department" on the second floor started to turn out inventions that were destined to set the pace for the new electrical industry.

It proved to be a very good thing that the shop and its tools were so inadequate. Thomson was forced to design his dynamos so small and compact that they could be made on the few old-fashioned machines at his disposal, which meant stark simplicity and the most economical use of every pound of copper and iron. The result was a dynamo with a unique spherical armature, high in efficiency for its purpose and better in all-round engineering than any on the market.

Edison and his mathematician Upton, at the time, were developing a big dynamo with a towering horseshoe frame, jokingly nicknamed the "long-waisted Mary Ann" by their competitors. Brush and the others were going in for scrollwork and ornamental cast iron which contributed nothing to electrical performance. But Thomson stuck to design for utility only. He could not afford to do anything else.

Wilbur Rice's first job as assistant electrician and test engineer at the plant was to scrub all the windows and whitewash the walls. Next, he and the Professor tackled the problem of training green workmen who had never heard of dynamos before and were entirely ignorant of how to build them. The two young enthusiasts did all the winding of wire themselves—nobody else could be trusted with that critical job. They also lent a hand at the lathes and other machines and ran complete tests on every piece of apparatus as it was finished. Every available moment that was left they spent in experiment, which, as Thomson knew, was an absolute necessity for future success. Every now and then they would have to knock off and run downstairs to help lift a machine or fight the flapping belts which were always jumping the pulleys of the overloaded little steam engine. Day in and day out they arrived at the factory at seven and on most nights stayed late to lay out shopwork for the morrow. There was no time for discontent, certainly none for complaining that they worked too hard.

It is the unselfish, lifelong contributions of such pioneers as these that have given the modern workman the tools of his trade. If he knew what those men went through he might be ashamed at his own ready habit of complaint. If his forebears had worked by his present standards, either of hours or skill, there would be no modern world for him to enjoy.

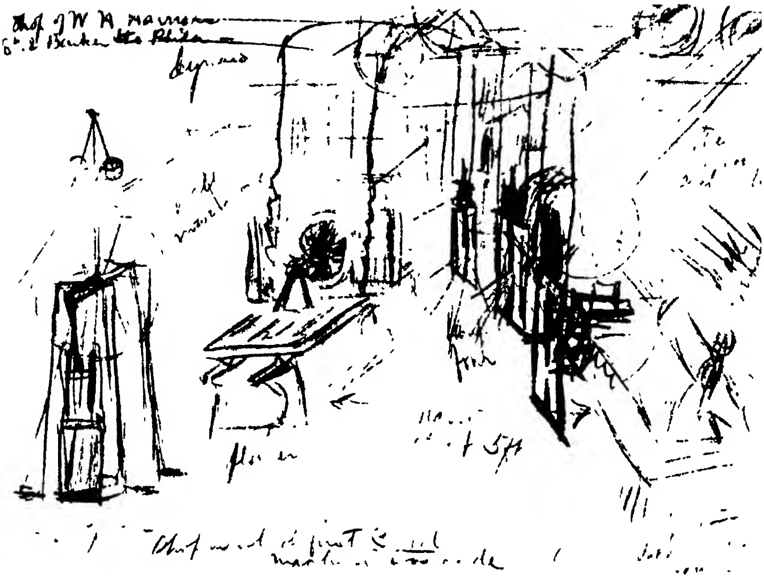
2

The first design problem that came along was a serious one, and had it not been solved it would have wrecked the business. Thomson decided that one good way to get ahead of his rivals was to build dynamos that could run more lights than theirs would. Ten lights per machine was the common limit at the time. He was anxious to be able to operate twenty and later even forty.

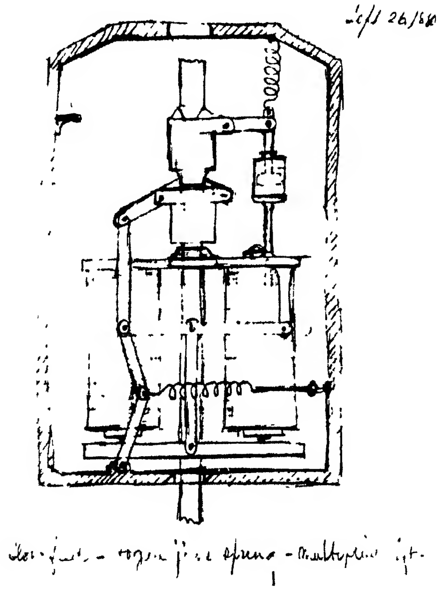
The difficulty was in handling the large voltages involved. Each arc lamp required about 50 volts. Twenty of them in series would need a thousand. It was no trick to build a machine to generate this high pressure in its revolving armature—only a matter of turns of wire and strength of magnetic field. But to get the high-voltage currents off the commutator and into the outside circuit was a different matter. After a few moments of running disastrous sparks began to leap between commutator bars until they were ringed with fire and the lamps short-circuited. Immediately the customers would be plunged in darkness and kept there till the sparking was stopped and the circuit restored.

Rice himself makes a dramatic story of how a cure was found:

> Professor Thomson tried many schemes to obviate this tendency to short circuit, but none of these methods was successful and the machine still remained too sensitive to withstand the rough and tumble use of those early days. He then resorted to two commutators in series, which gave conditions as satisfactory as those in the smaller machines.
>
> However, this introduced serious complications into the automatic regulator, which undoubtedly could have been overcome but which were unsatisfactory to Professor Thomson. He longed for the simplicity of the single commutator and insisted that some method could be devised to make it practical. I well remember his sparkling enthusiasm when he first told me of his final solution.
>
> He said, "Rice, I tell you what we will do, we will introduce a jet of air between the tip of the brush and the commutator."
>
> This was no sooner said than work on the experiment was started. He took two pieces of brass tubing and made jets at the end and connected them to short pieces of rubber tubing; I took one tube in my mouth and Professor Thomson took the other, and we proceeded to blow as best we could on the com-



Thomson's sketch of the crowded little Harrison machine shop



mutator. As long as we were successful in blowing we could maintain satisfactory commutation.

The Professor immediately designed a very beautiful and simple three-bladed blower which introduced a powerful jet of air at the proper time. We had this in operation in a few days on our twenty-light machine and found that it far exceeded our enthusiastic expectations. The machine worked perfectly; it seemed impossible to make it flash.

Thomson had found the solution to a difficulty that had been puzzling dynamo makers the world over. But he did not accept it until it had survived a brutal test. Rice continues:

He took an oil can and to my consternation deliberately squirted oil all over the brushes and commutator. Our delight knew no bounds when the machine continued to operate as quietly and happily as ever. The practical bearing which this had upon our business success was almost as great as that of the regulator itself. It meant that Thomson-Houston machines were practically fool-proof and could be run under extraordinary conditions of abuse and still give good service.

The affair was typical of Thomson's self-imposed standards. No halfway solution satisfied him. It must be complete and dependable—and inexpensive. It *had* to be, or the little manufacturing company could not survive.

The air-blast mechanism was quickly standardized on all Thomson-Houston machines and soon obtained an advantage in the market which was never lost. It survived as an exclusive Thomson feature till a dynamo was designed in which sparking at the commutator was negligible.

This early victory over a serious problem gave neither of the young men any feeling of complacence. Though their arc-lighting system could now compete with the best they were aware that constant improvement alone could hold the advantage gained. The Professor wanted to do more than merely keep up with the parade; he was anxious to make basic improvements that would put him at the head of it. So he looked ahead carefully to see what pitfalls might be in store as the arc-lighting art advanced.

Immediately the problem of lightning protection presented itself. How was the elevated wire, running on poles through the

city streets, to be protected as it grew longer and used higher and higher voltages? Some form of lightning arrester would presently be in demand.

The problem had been encountered already on long telegraph lines but was not serious because of the tiny voltages used in normal operation. On the power lines of the future, however, pressures of thousands of volts would be sure to give trouble. The moment a lightning bolt caused "spark-over" from wires to grounded poles the high-voltage arc-light current would follow, and a dangerous short circuit would be established. The question was how to provide an easy path for the lightning discharge but prevent the power current from using it also.

The Professor drew upon his store of general information for the answer. It was unexpectedly simple—a scheme based upon Faraday's early observations of the behavior of electric currents in a magnetic field. Thomson reasoned that an arc or spark jumping in air was the equivalent of a wire carrying current and would attempt to move sideways when surrounded by a magnet. Very well. Then let the lightning arrester consist of a spark gap placed between the poles of a permanent magnet. When the short-circuit arc formed it would be driven out of the gap by repulsion and extinguished.

Eagerly he described his idea to young Rice one morning. "I am certain it will work," he said. "But I'm going to be sure." Taking a big horseshoe magnet from the bench he held it close to the flame of an arc lamp burning on the testing rack near by. The light went out at once. He tried all the others in the room, one by one, and all succumbed in the same way. The principle of the "magnetic blowout," then, was sound.

Professor Thomson had made a major discovery; he must now apply it to the practical problem. His ability to design a machine that would work the first time was never demonstrated to better advantage. The first lightning arrester, built in New Britain in 1881, proved to be so nearly right that it was made and sold for years. It consisted of a pair of brass castings with long horns branching upward, forming a gap which increased in width from bottom to top. The narrow part of the gap was surrounded by the poles of a magnet.

In operation, one side of the arrester was connected to a power-

line wire and the other side to a ground conductor. When a lightning "surge" raced along the line it poured through the gap and was discharged. Power current instantly followed through the lowered resistance of the gap and a short-circuit arc was formed. But this arc could not remain between the poles of the magnet; the force of repulsion quickly drove it upward along the horns to the point where the gap was too wide for it and it would go out. By that time the high resistance of the gap was restored and no more power current could follow. The whole operation took only a fraction of a second, and the short circuit was too brief to do any harm.

No sooner had the lightning arrester become a regular feature of the Thomson-Houston system than the Professor thought of new uses for the same principle. The magnetic blowout, he believed, could be applied anywhere that heavy currents were being switched off. As dynamos grew in size and circuits increased in voltage serious trouble was to be expected in handling the current. The control of such currents by hand would be dangerous, even impossible. So the New Britain experimenters began work in the brand-new field of switching, applying the magnetic principle in many forms, with every promise of success.

Thomson was quick to patent the basic idea while its importance was still unrecognized. Within a few years his good judgment was amply demonstrated, for magnetic switches were in use everywhere. And in the control of trolley-car motors they were becoming indispensable. They are entirely so today. On streetcar lines, in subways, and on electric trains, whenever one hears a small sharp explosion and feels the train hesitate, a little switch has just operated, on the principle of Thomson's magnetic blowout, to cut the current off the motors. In this and other fields it remains one of his most fruitful and most important inventions.

3

Those New Britain years, however, were not by any means an unbroken succession of ideas developing into quick successes.

Elihu Thomson and his assistant spent most of their time in a never-ending struggle against small defeats and annoyances. Inadequacies of machinery, inexpertness of shopmen, lack of materials perpetually conspired with the plain "cussedness of

fate" and the parsimony of the stockholders to block their progress. Neither nature nor man wished to be shaken out of a comfortable routine. If an inventor insisted on advance he must do so against what appeared to be deliberate opposition at every turn.

Especially trying was the poor grade of the materials which the young electrical industry had to use. The miserable quality of the copper wire was a good example of this. It was drawn through steel dies then—not through jewels as it is now—and these wore out so quickly that a single length of wire would have different diameters at its two ends. The copper was drawn in short sections and then roughly joined by brazing or hammering, so that in every coil a series of lumps would occur, often with copper slivers sticking out through the insulation. Before it could be used at all, every inch had to be inspected and cleaned up—an extra operation that took many hours from more productive work.

The promoters of the American Electric Company insisted on buying their wire from a local stockholder whose feelings must be spared too much criticism. When the Professor found this out he called on the gentleman, a Mr. Plume, and told him his wire was no good. Mr. Plume readily agreed but did not see what could be done. He pointed out that his methods were as good as any other in the country.

Thomson suggested electric welding for the joints. "Oh," objected Mr. Plume, "that can't be done. Copper cannot be welded."

"Yes it can," the Professor retorted. "I've devised a process and a machine for doing that very thing."

But Mr. Plume was not interested enough to make the experiment. Thomson wished deeply that he could do the welding himself, but there was absolutely no time for it now. It would be folly to go off on such a tangent. His competitors would leave him behind in a minute.

Eventually the copper-wire situation improved as a new element was brought in. The makers of iron wire for ladies' bonnets were induced to supply the dynamo concerns with the wire the copper people could not seem to furnish. The high standards which the ladies had exacted from the bonnet makers for years soon produced long lengths of copper wire both uniform and smooth.

In a short time bonnet wire itself was a by-product and virtually unobtainable.

Another bottleneck appeared in materials for arc lamps. The glass globes used to shield them were far from satisfactory; clear glass made the arcs too glaring, while opal material was so dense that it confined some 60 per cent of the light within the globe itself. Nor were the carbon rods much better. They were crooked and of variable thickness; often they contained impurities which caused the lights to splutter or go out.

The coke manufacturers who made the rods as a side line took so little interest in the matter that the young electricians had to make their own arc-light carbons or give up entirely. Thomson, Brush, Weston—all of them—were up against the same trouble and had to invent their way out. Charles Brush was the first to develop a satisfactory carbon rod, but his process was long and intricate. First he had to procure the highest grade of carbon available, then crush it to powder, mix it with adhesives, and squeeze it into molds. After that it had to be baked in an oven and then cured. Only if every detail of the process was kept under rigid control was the final product successful. Brush tells the story graphically:

> Our first carbons were crooked and soft, and were made from gas-retort carbon which was difficult to pulverize and contained much ash. It was necessary to find some better material without delay. After an anxious and prolonged study I hit upon "still-coke," a by-product of the destructive distillation of mineral oils. It could be pulverized with comparative ease and was obtainable in unlimited quantities at small cost.
>
> But the early carbons made from still-coke shrank enormously in baking. Much experimenting was necessary to find out how best to work with this material. Special machinery and furnaces had to be designed for grinding, mixing, molding and baking.
>
> To decrease their resistance we electroplated the carbons with copper. This little scheme of covering them with just enough but not too much copper was the only easy invention that it was my privilege to make, and it paid well, considering its seeming simplicity. It yielded something like $150,000 in cash before serious competition set in.
>
> The very early carbons were sold at the rate of $240 a thou-

> sand. I say *rate*, because nobody thought of ordering a thousand at once. Fifty or a hundred were bought at a time. When the business increased a little we reduced the price to $150, and later to $62.50, on the theory that cheaper carbons would stimulate the growth of the industry. Our expectations were abundantly justified. While we lost money at first, we soon made it up in the sale of dynamos and lamps. Before long the consumption of carbons reached nearly two hundred million a year, and we made a handsome profit.

Plagued with other troubles at New Britain, Thomson wisely decided to postpone making carbons of his own, meanwhile buying the best he could from outside. There would be plenty of time to develop and patent a process when the dynamo problems were solved.

Difficulties with materials dogged every inventor of the day and kept him miserable all the time. It was not to be wondered at, for the electrical art had burst so suddenly on the world that its specialized demands often seemed strange and unreasonable. The same thing had been just as true in the early days of the telegraph, and especially when the Atlantic cable was struggling to span the ocean. The cable of 1858 had failed mainly because the wire manufacturers could not or would not make the copper uniform enough or keep the insulation up to the standard demanded by the engineers. Success had finally come in 1866 only after Sir William Thomson had rejected hundreds of miles of cable which did not come up to his specifications. Even after eight years he had not wholly convinced the makers that when an engineer writes a contract he means exactly what he says.

Professor Thomson was determined that the apparatus sold by the American Electric Company should be reliable and long-lived. To be sure of this he established rigid standards for every process of manufacture and enforced them by requiring careful measurements on every length of wire, every magnet, every dimension. Then when a machine was finished it had to be given careful tests to see that it would behave as represented.

The attainment of this high ideal was made very difficult by the complete lack of measuring instruments. What few there were on the market were unsuitable for electric power work. Therefore Thomson and Rice were forced to build their own. Having little

money and no spare time, these were totally without frills, just as crude as the work permitted. A Wheatstone bridge was the basis for the whole outfit and had to be used in connection with standard resistances to determine the voltage and current, just as in the Franklin Institute tests of three years before. The resistances Thomson had to borrow from the High School in Philadelphia till he could find time to build copies of them for himself.

With these primitive instruments the first Thomson-Houston dynamos and lights were nursed into public service. But the waste of time in making routine measurements the hard way finally sent the Professor to New York to see if real instruments could not be bought. He found that they could not—at any price—for the simple reason that none had yet been invented. Finally he wheedled a lumbering big galvanometer out of the Western Union people and took it home to use as best he could.

The end of it was that in desperation he and Rice invented voltmeters and ammeters of their own and thus, without intending to, became pioneers in that vital field also. Thomson meters of the motor type were the first to reach the market a few years later; their descendants are still in use—nowadays by the millions.

Notwithstanding all these troubles, the two young men found many chances during the day to talk about the future. The upshot of their discussions was usually an experiment to try out some new idea, and more often than not a patent application resulted. When a new device reached the patenting stage they would ruthlessly crowd their regular duties to make time for building models and writing specifications. There being no money for anything but bare necessities, Thomson himself did service as model maker, draftsman, and attorney.

The making of the models alone was a job of great skill and precision. The Patent Office required them to be built of wood, "practical" in every detail. For years the Professor constructed every one, though he was filing patents at the rate of nearly one every month.

When it came to the specifications he prided himself that he could write them more clearly and briefly than anyone he could have hired. He did not overestimate his skill. Some of his most valuable patents were later sustained in court because their

language exactly described the claims and was not open to misinterpretation, even by the cleverest opposing lawyer.

So the New Britain venture began, full of trial and tribulation, burdened with disappointment and annoyance, but rich in ideas which promised great things for the future. At the age of twenty-seven Professor Thomson had proved himself a businessman as well as an engineer.

Chapter 12

I

An inventor's life in New Britain certainly promised to be a lonely affair. Now that the novelty had worn off the new electric company the citizens paid it no attention whatever. These hardy Connecticut Yankees were extremely busy making Stanley tools and laying up their fortunes. Social activity, so far as Elihu Thomson was concerned, did not exist.

This rather disappointed him. For all his vigorous prosecution of his many professional activities his warm heart craved associations of the kind he had so cherished with Greene. There were few to be had. Churchill was friendly but confined himself wholly to business. He even acted rather secretive and let it be known that he was immersed in some invention of his own that could not be divulged until it was finished. The Professor could have been hurt by this snub if he had permitted himself the luxury. He would have been more than glad to advise the lawyer or even to collaborate with him. That being impossible he dismissed it from his mind and retired into the little group of "experts" which surrounded him at the factory.

There were only three of them, all youths in their teens, and Thomson found himself acting more as a father to them than as an associate. At first this seemed a rather barren relationship; he could not help longing for the contacts with adult minds which he had enjoyed so much in Philadelphia. At twenty-eight he wanted to sit at the feet of men older and wiser than himself and learn from them, as the younger men in Europe were even then learning from veterans like Tyndall, Sir William Thomson, and Helmholtz. Yet he knew that this could never happen. He was born to be a teacher, not a pupil. So he accepted the responsibility cheerfully and fell back upon his mother's charming faculty of being at once an adult and a child in the presence of youth.

The three assistants—Rice, George Emmons, and a boy

named Seymour—were indeed earnest young men who presented no problem of discipline since they worked much too hard anyway. Thomson took a special delight in trying to blast away their abnormal gravity with the gentle, rather elementary humor that was deep in his nature but rarely found an outlet. The more he did it the more fun it was. Presently he discovered in himself an incorrigible boyishness which never failed to hold interest and to act as a backdrop against which more serious thoughts could be set in their true perspective. This sense of showmanship he never lost. Even at eighty, and clothed with every scientific honor the world had to give, he was still playing his gentle practical jokes and making his mild but penetrating cracks to emphasize the meaning of some scientific point.

The four of them lived in lonely state at New Britain's principal hotel, the Strickland House. Here at breakfast each morning the Professor would open up with a performance which put his protégés in the proper frame of mind for the day's work. A pop-eyed German waiter with no discernible sense of humor officiated in the dining room, and the Professor used him for an involuntary stooge. The first time the waiter asked Thomson if he would have a dropped egg the Professor demanded gravely who had dropped it. This of course got a laugh. The next day the waiter asked the same thing again. Thomson made the same retort and got a bigger laugh still. Thereafter the situation improved steadily in flavor, for the waiter never discovered why his tormentor thought it was so funny. It was his hurt face, more than the anemic joke itself, that kept the laugh green.

Thomson was on the lookout for every chance to rib the poor German. One day when he was served an unpalatable dish disguised in cream sauce, he demanded to know what it was.

"Picked-up fish," said the waiter reproachfully. "A good New England preparation you should know."

"Picked-up fish, eh?" mused the Professor, scrutinizing it on his fork. His audience held their breath waiting for the inevitable next line. It came when the examination was finished.

"Yes. Well, who picked up this fish, waiter? And where?" The waiter stared at him as the others roared. "I won't eat it," he said. "Go and drop another one of those eggs."

By and by Rice and Emmons moved to the boardinghouse of a

Mrs. Moore, to save expense by rooming together. George's seriousness soon returned. This was not to be wondered at for he was charged with the bookkeeping responsibility for the firm. One night he sat up hour after hour poring over his accounts. The light kept Rice awake, and he finally demanded to know what was the trouble.

"I'm a cent out on my double entry," said George. "I can't find the mistake."

"One *cent!*" growled Rice. He piled out of bed and fished a penny out of his pants pocket. "Here, put this in the treasury with my compliments. Now, for goodness sakes, go to bed."

George went reluctantly. "Just the same," he said in the dark. "This company has to count every penny."

Rice, who had caught a little of the Professor's jocularity, chuckled. "The trouble with you, George," he gibed, "is that you are thinking of the shoe business, where they split hides all day. You can't split pennies the way you do leather."

Though a trifle musty now that they are retold after sixty years these sophomoric bits of humor did their part in creating the electrical industry. The more vigorous the mind, as a rule, the cruder it is apt to be in its moments of relaxation. Certainly this was true of Elihu Thomson, who loved to balance the profoundest of observations with a twisted word or a tortured pun.

All jokes notwithstanding, it was evident to the four young men that the American Electric Company was not prospering as it should. George Emmons was quite right—accounts were concerned mainly with pennies. Though Professor Thomson never complained, he was exceedingly dissatisfied with the lack of sales. He knew that his dynamo was superior to any other on the market, yet it was not getting its share of the business.

The explanation was obvious. The backers were letting the company slide. They were not conducting its affairs with the "reasonable diligence" required. Thomson made up his mind to bring the issue to a head. But just as he was about to do it, a sudden tragedy occurred that shook the company to its foundations.

Frederick Churchill committed suicide.

It was a stunning blow, at first without explanation. The man who had organized American Electric, who had lured Thomson

away from his life in Philadelphia, who was the inspiration and guidance of the backers, had killed himself, at the moment when the business opportunities were greatest.

The mystery was soon cleared up. Churchill had ended his life in a fit of despondency over an invention that failed. For some time past he had been secretly working on a machine which he hinted would make a fortune, but which he refused to discuss with anybody, even his wife. When at last it was finished he had slipped away with a model of it and had been gone some time. He had come back a changed man—without the model—had gone down into his cellar workroom and shot himself.

Thomson was greatly upset. He had liked Churchill and believed in him, and was a good friend of Mrs. Churchill as well. Now he knew that she would blame him entirely. She would say that he should have warned her husband that his invention was worthless. It would do no good to point out to her that his advice had not been asked. She would insist that he should have guessed at the situation and prevented it. And he was in a most uncomfortable position professionally. The scandal was bound to affect the business adversely, and the loss of Churchill's leadership would further discourage the already weakening backers. The great sacrifices he had made to come to New Britain were likely to be in vain.

On the hopeful side was the excellent three-coil dynamo and arc-light system, as well as the various patents that had been obtained. More important, the team of Thomson and Rice had proved itself capable of a great future if only given money and tools to work with. Obviously these assets must be safeguarded before it was too late. In addition to all his other duties he would have to make up for Churchill's loss by increased business activity of his own.

2

It happened that in the latter part of 1881 the management made a feeble effort at promotion by sending a dynamo and a few lights to an exhibition in Boston. Angrily the Professor visited the exhibition himself to see what was being done to turn the opportunity to account. The answer, he found, was nothing. But on walking down Tremont Street that night he was attracted

by a brilliant display of arc lights which were drawing quite a crowd toward a store. It was, he had to admit, an impressive sight. Two bright arc lamps were hung over the sidewalk outside, and six or eight more made the interior as brilliant as day. Considerably piqued, he went in to find out what rival lighting system could be responsible.

The Professor was greeted effusively by a Mr. Goff, a promoter, who urged him to buy some stock in a new enterprise called the American Electric Illuminating Company.

"Really?" ejaculated the Professor.

"Really what?" asked the salesman.

"Nothing. But would you mind telling me who manufactures these lamps and the dynamo that runs them?"

"Oh, them," laughed the salesman. "A little concern down in Connecticut. But that's not important. We shall simply buy the outfits and then sell them again under our own name. Now we are introducing the stock at a bargain . . . "

But Thomson brushed him aside and pushed through the crowd to the cellar stairs. Below, as he expected, was one of his own faithful little three-coil machines—a dynamo, in fact, that he and Rice had just lately put through its tests at the factory. The management had been in a hurry for it but had omitted to say who the customer was.

Now quite furious, Thomson left the store and got himself back to New Britain as fast as he could. It was altogether nonsense that things should go on behind his back. Laxity in the conduct of the business was bad enough, but dishonesty was intolerable. At the first possible minute he went to see the board of directors.

By apparent coincidence these gentlemen sent for him at the same time. Before he could even say a word they handed him a contract—a new one intended to replace that on which the company was founded. He looked it through rapidly. On the face of it they were proposing to hire him at a better salary for a longer term of years than before. But long practice with legal verbiage warned him to look for a hidden intent. It was not hard to find. "What they are after," he told himself, "is to put me on the shelf. Well, let's see if they can!"

Aloud he said, "Gentlemen, you are planning to sell the company. That is plain. Who wants to buy it?"

"*Sell* the company?" said the directors. "Whatever gave you that idea?"

"This contract. You know well enough that the original agreement has not been lived up to. You want to get your money back quick, before I demand the return of my patents. But you can't safely do so till you have tied my hands securely."

The directors looked at each other and raised their eyebrows.

"Well?" said Thomson.

"The United States Lighting Company has made us an offer," President Parker admitted finally. "We propose to accept it."

"Very well," said Thomson. "I am perfectly willing. But I see no preamble in this document saying that the new company must carry on the work with due diligence, as per the first contract."

"But that is understood, of course," the directors protested in unison.

Thomson replied quietly, "If it is understood, put it in the preamble to the new contract."

The room was filled with the keenest business minds in New Britain. And the Professor was alone against them all. They parried him skillfully, and seemed to have a plausible answer for every argument. But he stuck to his guns, and the afternoon passed. Finally they appealed to his loyalty to the company. They said, reproachfully, that they had anticipated trouble with Houston, who would surely be thinking of his own welfare. But as for the Professor—

"See here," he cried, thoroughly exasperated. "I *am* the company! Any question of loyalty is absurd."

"I'll show these people," he thought to himself. "If that is the way they estimate me, they will get to know more."

The directors seemed hurt and said that if he really *was* the company a preamble about "due diligence" was equally absurd.

Thomson picked up his hat. "You need not expect to hear from me further unless you put that preamble in the contract," he said, and walked out.

This firm action broke up the deal. The United States company did not dare to buy an inventor who wouldn't sign contracts unless he wrote them himself.

The Professor went about his affairs as if nothing had hap-

pened. But he did not fool himself. The American Electric Company was on its way out. It would soon be necessary for him to take back his patents and start again. It was a maddening situation for a man whose mind overflowed with ideas and whose hand could invariably turn them into practical machines. There was so little time to spare! His competitors were marching ahead every day. He could not afford to drop behind them.

Fortunately the showdown was not long delayed. Early in April, 1882, the Professor learned that his board of directors had sold him out. They had done it hastily, behind his back, but with a pious show of legality which they thought would put him off the scent. The transaction had been simplicity itself—the sale of a majority of the company shares to George W. Stockley of Cleveland, Ohio.

Stockley, of course, was the president of the Brush Electric Company. The ruse was entirely plain. The Cleveland people wished to get control so that they could remove the Thomson-Houston lighting system from the market. Possession of the bulk of the stock, they assumed, would give them the right to do this.

Thomson could not suppress his amusement. It was the greatest compliment the three-coil dynamo had received yet. Evidently Brush feared its competition and was trying to kill it by the ancient method of Wall Street.

The Professor was not disturbed about the legal outcome, knowing that the original contract would defeat Stockley in the end. So he decided to say nothing for the moment, while the Brush people got themselves thoroughly entangled. Then he would have some fun with them. He judged that they had brought it on themselves.

So, instead of reading his company directors the riot act, he sat down and wrote a simple letter to them, offering to surrender the stock which he held and requesting the return of his patents. In this he had the backing of Houston, whose signature he got on a visit to Philadelphia. When the letter had been mailed he went calmly about the business of seeking new backers for the company. A turn of fate soon brought him the men he needed. Ironically, they came through Edwards Goff, the Boston promoter who had pirated the Thomson system a few months before.

In the gathering trouble with the company directors the

Professor had not had the opportunity to force this man to give up his fraud, and Goff had gone merrily on selling stock and attracting considerable attention in Boston.

3

At this time—1882—the neighboring city of Lynn, Mass., was becoming the shoemaking capital of the world. This industry had already attracted some of the most astute businessmen of the day—men of broad vision and pioneering spirit who had the talent for profitable enterprise. Two of these men, Silas A. Barton and Henry A. Pevear, were constantly on the lookout for new projects to put their money to work.

Barton had been following the progress of electric lighting with great interest for some time. When it was suggested that the Lynn Grand Army Post install arc lamps in its new assembly hall, he was invited to look into the matter and choose the equipment. Barton agreed and asked his friend Pevear to go with him to Boston where he had heard some lighting systems were on exhibition.

Finding nothing promising during the day the two men stayed over into the evening and were attracted to Goff's store by his sidewalk display on Tremont Street. They stood a while listening to the promoter's harangue, amused at the man's overweaning confidence. Being old hands at the business game, they were not taken in for a moment. Then Barton said,

"This man is a fool, but his arc lights do work. Wonder where he got them?"

"We might ask," said Pevear.

"We'd never find out that way," Barton objected. "Let's look for ourselves." Taking advantage of the crowd they slipped down the back stairs to the cellar, where they found Thomson's six-light dynamo humming away faithfully by itself, driven by a diminutive steam engine. On the brass nameplate they read, "Manufactured by American Electric Company, New Britain, Conn."

"Fine," said Pevear. "You can write them a letter."

Barton ignored him for a moment. He was busy watching the smooth operation of the dynamo and its automatic regulator. "This looks like good machinery to me," he said finally. "I'd like to know the man who designed it." They returned to the

sidewalk and examined the lights. These, too, were simple and sturdy in construction, and obviously efficient. As they walked off down the street Pevear said,

"I know what you're thinking, Silas. You want to get into this electric-light game yourself."

"Exactly. Why can't we get this kind of a system for Lynn? In fact—" he stopped short in the street—"here's a better idea! Why don't we go in with this inventor, whoever he is, and back him? If I'm any judge, he needs money and good promotion. They all do. We ought to rescue him from a highbinder like Goff."

Pevear was left a trifle breathless by his friend's sudden enthusiasm. But before their train reached Lynn he had recovered and made up his mind to go along. Next day, not saying a word to anybody, the two men started off for New Britain.

When they arrived at the plant, Thomson was out of town. But the office boy introduced them to young Wilbur Rice. Even at twenty the youth had a strong business intuition. He instantly sized up his visitors as important people. They must be given every possible consideration. He must contrive to put on as good a show as he knew the Professor would do if he were present.

Rice took the Lynn men through the plant from top to bottom and kept up a running fire of explanation in the best Thomson tradition. He concealed nothing, but told them of the many plans "our electrician" had for improvements in the field: lightning arresters, meters, switches, dynamos of greater power and efficiency. When he saw how impressed they were he took a flier into the business situation of the company and described the unsatisfactory two years Professor Thomson had spent trying to get action. "We are powerless," he said, "because our financial backers are afraid of their own shadows. Why, if you could just see my Professor . . . "

Barton gave Pevear a significant look. "I think we can see him perfectly," he said.

Rice had convinced his visitors that they were on the right track. Without hesitation they ordered a dynamo and set of lights and took the first train for home. They left word for Thomson to come to Lynn at once to talk over the future of the company. Rice was overcome with delight. At last he had done something to repay his Professor for his inspiration and guidance.

Back in Lynn Barton moved fast. Calling a number of associates together he persuaded them to organize the Lynn Electric Lighting Company, to supply power for a commercial arc-lamp system. Soon the dynamo arrived from New Britain and was installed in the basement of a department store. On May 21, 1882, Market Street—the town's principal business thoroughfare—suddenly blazed with electric lights—the first commercial street lighting in New England.

Meanwhile Professor Thomson had returned to New Britain to find his young assistant brimming with the news. "Go to Lynn as fast as you can," Rice cried. "These people want to buy the company!"

Realizing that there was no time to lose, the Professor hurried off, wondering just how much sagacity shoe manufacturers could be expected to show in the electric-lighting business. At any rate, it could not be less than the locksmiths of New Britain.

The industrious Barton was waiting for him with preliminaries all arranged. He had already picked out half a dozen of his well-to-do friends and had induced them to form a syndicate to buy the American Electric Company. Pevear had been the only one to introduce a note of caution. "We're taking a good deal of a chance," he had objected, "in backing this man Thomson sight unseen."

"Wall Street took a chance on Edison at the beginning," Barton had countered. "And I think we've got another Edison."

Pevear had finally agreed to join the syndicate, provided that a young shoe man by the name of Charles A. Coffin was willing to participate in the strange new enterprise. Coffin, at thirty-eight, was a hustler and had the reputation of having the smartest business head in the city. Pevear trusted his judgment more than he did his own.

There the matter stood when Thomson arrived in town. The Professor was in a buoyant frame of mind. It was the twenty-ninth of March again, this time his twenty-ninth birthday. That was surely an omen of good luck. He hunted up Barton immediately and told him he had come to talk business.

Barton was charmed with him the minute he saw him. The Professor's quiet, courteous manner, his evident mastery of his subject, his straight talk about his financial difficulties, made it

plain that he knew exactly what he was about. Barton decided he had made no mistake. This man would be a good business risk. Immediately he sent messengers to round up the proposed syndicate. Charles Coffin agreed to join the discussion.

That meeting in Barton's office was a historic one for the electric-lighting business. Its success stemmed entirely from Thomson's ability to command confidence and respect the minute he began to speak. On this occasion, though he realized it was one of the most important moments of his life, he made no speech but described to them frankly the difficulties he was in and the faith he had in himself and in the future of the industry. He said he believed absolutely that if the Thomson and Houston patents were given energetic exploitation they would bring great financial return. "And you need not fear," he concluded, "that we shall fail to do our part if you will do yours."

When he had finished his forthright statement there was silence in the room. Everybody was looking at Coffin, waiting for him to speak. Pevear finally said, "Well, Charles, what do you think?"

Coffin answered simply, "Why do we delay? Let us go ahead and do it at once."

It was a remark that afterward became a byword in a great industry. Again and again Thomson would be greeted with those welcome words when he proposed something new, "Go ahead and do it. Don't mind the expense. Do the thing you think is right!" Coffin believed in his own judgment, and he was seldom wrong.

Someone reached for a pad of paper. An agreement was drawn and signed before anyone had left the room that day. The Lynn syndicate would take charge.

Chapter 13

I

There were a few loose ends to tie up before the Lynn syndicate could begin to function. One was the little item of the Brush Electric Company, which had so recently bought control of the New Britain concern for the purpose of putting it out of business. Thomson had told the story of the transaction to his new friends and they had had a good laugh over it. They assured him that everything would come out all right, given a little time for friendly negotiations.

When he got back to New Britain he found that George Stockley had come east to see his new property for himself. Thomson showed him the factory and noted that his competitor seemed undismayed at its insignificance. When the Professor asked him how he intended to proceed, Stockley mumbled something about letting things go on as they were until arrangements could be made to move the establishment to Cleveland. He was, he said, very kindly disposed toward the Professor and his assistants and would naturally keep them on as long as he could. He hinted strongly that there might be a place for Thomson in the Brush organization.

"In which case," he said, "I shall have bought assets of great value."

Thomson looked at him with a disarming smile. "Mr. Stockley," he said, "I do not want to upset your plans. But the thing you have bought is not a business but a lawsuit. And you're bound to lose it."

"I think I understand what I have bought," said Stockley easily, "and I certainly don't intend to have any trouble."

"Then you had better sell out again quickly. Please look at this contract." Thomson had pulled a copy of the original American Electric agreement out of his pocket. He had it with him all the time now.

The Brush president scanned the document hastily.

"You'll notice the stipulation," the Professor was saying, "that if the business is not carried on with reasonable diligence the patents revert to Houston and myself on tendering our stock. We have already tendered it. The former owners did not fulfill their contract."

"Damnation!" Stockley said. "Let me read this thing carefully!"

Thomson looked at him curiously. "Do you mean to say you bought control of this company without reading that contract?"

"I assumed it was the usual form of patent agreement, of course. But this . . . ! If I had known this 'reasonable diligence' clause was here I wouldn't have touched the stock. I wouldn't have had anything to do with it!"

He seemed much perturbed.

Thomson suggested mildly, "Would you perhaps like to sell that stock again?"

"Look here!" Stockley shouted. "What sort of a manipulation is this?"

"It's all plainly set forth in the contract," Elihu Thomson said.

And the end of it was that the Lynn syndicate picked up control of the American Electric Company without any trouble at all. Moreover, in a few years they had the pleasure of buying the Brush company itself, with the services of Charles Brush included. It should be carefully recorded that Brush was not personally involved in the attempt to destroy his competitor. It was Stockley's idea entirely.

It was necessary for the Lynn financiers to leave the company where it was for the present, as its charter forbade its removal without an act of the Connecticut Legislature. So a petition to this end was started in Hartford, and Thomson and Rice settled down for the remainder of 1882 making every effort to catch up on the many things they had lacked time and money to do. American Electric started to hum; additions were made to the factory and more men were hired. Designs for a twenty-five-light dynamo were begun. Rice received a raise, and Emmons began counting dimes instead of pennies.

On the crest of the wave again, Professor Thomson decided to

assert himself in the life of New Britain. Soon he had revitalized a moribund group called the New Britain Scientific Association, had become its president, and started upon a series of lectures on electricity. His name began to be mentioned in the local *Herald* from time to time, especially when he drew capacity audiences to the Normal School Hall. He was on the way to becoming a prominent citizen.

Presently the Professor and his young associates were being asked to dine at the best homes. One family in particular, by the name of Peck, was especially cordial. The Pecks were cousins of the Stanleys, who had helped finance American Electric; Mr. Peck was high in the Corbin lock works, and his son Edward was the Professor's office boy.

Ed Stanley had introduced Elihu to the Pecks one Sunday afternoon, saying that he "ought to know some females for a change." Thomson had consented to go reluctantly. He had no desire to change his long habit of aloofness from the fair sex.

But the moment he met Mary Louise Peck he changed his mind. Her quick intelligence and her sympathetic understanding captivated him at once. She was twenty-six years old at the time, a quiet, conscientious young lady full of generosity and the capacity for loyalty and affection. Except for his mother Elihu could not remember ever to have seen such an absorbing creature anywhere.

Unashamedly he talked to her about his tangled professional affairs, that first Sunday afternoon, and she responded valiantly, though she had only the vaguest idea what it was all about. But presently he ventured a remark about the outdoors, and the ice was broken. Delightedly he discovered that she loved nature just as much as he did, and in a moment they were lost in a discussion of the birds and flowers, and he was recounting to her his adventures on trips he had taken to the mountains.

Besides Louise, the Peck family included two brothers and a sister, Carolyn. "Carol," as she was called, had just turned thirteen, and during that first afternoon of magic discovery, she hovered in the corner of the parlor and observed with wide-open eyes. Instinct told her that Mary Louise was interested in this good-looking gentleman. The thought that "Minnie"—the faithful one, the stand-by of the family, the captain of the household—

should acquire a beau at her advanced age, was something that would keep Carol awake for many a night to come.

The friendship developed slowly that winter, and not without complications. Louise, as Elihu eventually was permitted to call her, was independent-minded to a fault and could not be dominated. She had a host of girl friends and seemed to prefer them on many occasions when Elihu thought he should have entertained her himself. In addition to that, both Rice and Seymour took a sudden interest in her and introduced annoying diversions.

As time went on Elihu found it quite impossible to call on the Pecks alone. The minute he started out of an evening his faithful assistants were at his heels. The three of them would arrive on the porch separated by a short interval, and the Professor would quickly ring the bell, hoping to elude them once inside. It was no use. Evening after evening the three sat in a circle in the parlor, while Carol lurked silently in the shadows. The conversation remained of the most general sort.

Carol, however, was aware that the Professor's stock was going up. Her sister's increasing sensitivity to pointed remarks and gibes proved it. Just to make sure she wrote the word "Elihu" on a slip of paper and pasted it to Minnie's bedroom mirror. Next morning the offending reminder was gone. So she remarked innocently,

"Elihu is a very strange name, isn't it? Do you approve of such a strange name, Minnie?"—and then cocked her ears to catch the exact note in her sister's response. Mary Louise's reply left no doubt that the affair was becoming serious, "Please, *never*, Carol, do such a horrid thing again!"

The interference of Seymour and Rice finally drove the Professor to a good-natured subterfuge that yielded results. Louise's cousin, Kate Doen, was also an attractive young lady, and with a friend made up a trio that stuck together valiantly. Elihu hit upon the plan of calling on all three in rotation, appearing to show no favor. He had not done this for long before his satellites were at his heels again.

For some time the thing remained a game. The three girls never knew which young man was at the door when the bell rang. Nor could the assistants be sure where Elihu might be on any given evening. In this way he managed to capture Louise occa-

sionally for himself. With that problem solved he faced the serious business of courtship. For he had decided to propose to Miss Peck as soon as she would let him.

It was by no means as easy as he had expected. It seemed impossible to make the simple words convincing, and the more he screwed up his courage to try them the less Louise seemed ready to listen. Finally, in desperation one evening, he gave up trying and suggested that they go out in the yard and look at the stars. She agreed at once.

If she had expected the proposal under these romantic conditions she was disappointed. Elihu was only trying to get back on familiar ground, postponing the important question till he could rehearse it thoroughly at home. The stars understood and reached down their friendly beams to give him aid. In a few minutes he had launched into such a thrilling talk about the depth and beauty of the universe that the girl quite forgot everything and listened to his soft, well-modulated voice for a long time, entranced. Only after they had explored the whole heavens and she had dutifully recited after him the names of the constellations one by one, did she realize that this forward young Professor had his arm around her—tightly—and did not seem disposed to let go.

It was a surprise to him, too, and they laughed and moved closer.

"Louise, will you marry me? I want you to," came next, and so naturally that there was no way to separate it from the beautiful words he had been saying. And when she did not answer, he understood that of course she meant yes and was quite as unable to return to earth as he himself.

As with so many great men, it was the beginning of a perfect relationship. Symbolized that way by the winter stars, their marriage, a year later, remained for thirty-two years the complete understanding of two people, strong in mind and heart, who kept their individual integrity and yet merged into one. In many respects Elihu and Louise were utterly opposite; she was a "lark" who went to bed with the sun and rose with the morning mist. He was an "owl" who sat in his laboratory till long after midnight, staring at the heart of his problems with unblinking eyes.

But always they loved the stars and shared them, as the stars

themselves had shared their new happiness that night in the spring of 1883 in New Britain.

2

One day early in 1883 the *New Britain Herald* said in its personal column:

> The lightning has struck twice in the vicinity of Pearl Street and sparks have been flying ever since.

The editor was referring to the fact that Wilbur Rice as well as Elihu Thomson had become engaged. Kate Doen had also succumbed; the Professor's little trick had proved to be a double-edged sword.

It was his first taste of publicity and it annoyed him. He believed, with Faraday, that love was a private affair. In one of his notebooks the great Englishman had written:

> What is Love? A nuisance to everybody but the parties concerned. A private affair which everyone but those concerned wishes to make public.

But the young professor soon forgot this invasion of his privacy in a misfortune which overtook him that same spring. Hardly had Mary Louise accepted him when she was forced to leave New Britain in order to take care of her uncle's children. Their mother had died and there was no one else to keep the family together. This was a sad blow to the lovers, who had planned a glorious New England spring of exploration.

Elihu made the best of it by plunging into his work even harder. The Lynn syndicate was standing squarely behind its promises and there was plenty of energy in their management. In February, 1883, at a meeting in New Britain, Charles Coffin reported that favorable action in the Legislature would soon permit the company to be moved to Lynn. The Professor was delighted with the idea, especially as it would mean being close to Boston, which had already charmed him. He had never lost his love for the intellectual atmosphere of a big city. Except for Louise, New Britain had given him nothing but regrets.

Coffin also thought the firm's name should be changed to the Thomson Electric Company, since it would deal wholly in the

Professor's patents. But the Professor insisted on Thomson-Houston. It was typical of him to do this in the face of the shabby treatment he had received. Houston had done nothing to earn such a favor; in fact he had been growing steadily more of a nuisance since the New Britain move.

Openly in Philadelphia he was describing the arc-lighting inventions as "my system" and deliberately playing down Thomson's major part in them. He had also kept up a running fire of annoying letters to the Professor, demanding more money and obstructing the conduct of the business whenever legal documents needed his signature. Yet in the face of all this the Professor insisted on perpetuating his name in the enterprise. All that he would say was:

"I know that Houston will be sorely hurt if he is left out."

Thomson's desire prevailed and Houston's name became synonymous throughout the world with pioneer electrical inventions. It is still known today in many European countries, though as the Professor once wrote to his friend Colonel Crompton, "I originated the experiments and Professor Houston was present."

It was the syndicate's plan to lease and occupy a good-sized factory already being built in West Lynn. But as the plant would not be ready until fall, Thomson had several months yet to mark time. They hung heavily on his hands. Louise had gone and there was nothing left but memories.

The spring of 1883 offered an unexpected escape. The city of Cincinnati announced in the press that its annual industrial exposition would give special place that year to an electric-lighting contest. All the dynamo makers, both arc and incandescent, were invited to enter their machines. Thomson immediately proposed to his Lynn backers that the company get into the competition and was delighted to find them ready to go the limit. They directed him to prepare the best exhibit possible and to spare no expense. "Never mind what it costs," Silas Barton wrote him. "We want you to win!"

Barton went to Cincinnati himself to make sure that no opportunity was missed and to see that Thomson did not skimp matters from his long habit of frugality. The Professor found this kind of support most refreshing. Never before had he had the proper resources to work with.

The competition proved to be very much like the Franklin Institute tests of five years before. T. C. Mendenhall, professor of physics at Ohio State University, headed the jury of awards, with other educators as his aids. The jury's handyman and technical assistant was a student of Mendenhall's, a local farm boy who had made up his mind to batter his way into the electrical game no matter how much work it meant. His name was Albert Rohrer.

Mendenhall had chosen Rohrer because of his resourcefulness and determination to get ahead. As a mere boy he had worked nearly a year to save up money to visit the Philadelphia Centennial. He had talked of nothing but electricity since and had worked his way through the university with that one career in view. This was his first chance to prove what he could do independently.

The scheme of the competition was complicated and consumed several weeks' time. Being heavily occupied with teaching, the jury members met to make the dynamo tests only on Friday nights. From Sunday till Friday afternoon young Rohrer was all alone in the hall, and it was his job to set up the machines, find out how to connect them, and make the preliminary runs.

His worst difficulty proved to be in measuring the power delivered by the steam engine to the various dynamos under examination. At the moment only an ancient "belt dynamometer" was available, and Rohrer was much disturbed to find that the dynamos consistently showed efficiencies of 96 or more per cent. In one case a machine of Edison's did better than 100 per cent, delivering more power than the engine put into its shaft.

Mendenhall was a little suspicious of Rohrer's figures when he heard of this. It was a bit too good, he said, even for Edison. On repeating the test himself he found it was not Rohrer but the dynamometer that was at fault. Fortunately Professor Brackett of Princeton had just developed the early form of the "cradle dynamometer," and Mendenhall got his permission to build one in Cincinnati at the last moment and so saved the tests from failure.

Response to the contest proved to be disappointing. There were only three makes of dynamo represented—Edison's incandescent, Thomson's arc-light, and machines of both types which Edward Weston had designed for the United States Lighting Company. Cincinnati being in the midst of the Brush stronghold, that company haughtily sent a dynamo to the Exposition but refused

to enter it in the tests, thinking that it had the market in that region already under control. It was a bad mistake, for it started the Brush dynamo into its eventual eclipse.

The Professor was delighted, however. Here he was side by side with Edison, his greatest rival. The prize he meant to win would put him on an equal footing with the genius of Menlo Park. And he was glad, too, of the chance to meet the United States company face to face and shake some of the confidence out of the people who had tried to buy him off the year before.

Mendenhall opened the contest with a kind of oral examination at which he asked the representatives of each concern to stand up and give descriptions of their machines. In the course of the quiz, he slyly interjected electrical questions which had nothing to do with dynamo design but which, he thought, would tell him something of the ability of the men responsible for lighting development.

Thinking to put their best foot forward, the United States company had sent two men named Curtis and Hine, one a lawyer and the other a salesman. Both were on their feet immediately the examination began, laying down a skillfully prepared barrage of facts and claims. If half of them had been true they would have won the competition hands down. Mendenhall listened attentively until they had finished their act. He was fully aware of the tricks of this very tricky trade. And he noted that these two carefully talked themselves around the questions of general theory which they obviously could not answer.

When Elihu Thomson's turn came he made a statement which was no sales talk at all but the plain truth that he knew he could back up. The jury listened to him absorbed. And when he met the theoretical questions with a force and clarity that were both charming and enlightening the members looked at each other and nodded. Here was a young man who knew what he was about.

"Now, gentlemen," said Mendenhall with a twinkle, "I'll tell you what I'd like you to do. Just sit down and write out for us what you've said here. Put these claims on record and we'll see how well the machines measure up."

The Brooklyn pair spluttered a moment and then declined, saying they would let their machines "speak for themselves." Thomson, however, had seized a pen and paper and was indus-

triously at work writing an exact analysis of his three-coil dynamo, describing every original feature and giving the technical reason for its use. When it was done he had covered seventeen pages of foolscap in his earnest, legible hand. "This is what my machine will do," he said quietly, handing the report to Mendenhall.

"You mean," the older man smiled, "that the Thomson-Houston dynamo produces something more tangible than hot air?"

"I will let it 'speak for itself' " quoted the Professor, grinning back.

That evening Curtis and Hine gave a dinner for the exposition officials and the contestants, including Rohrer. Soon the talk was skillfully directed toward the merits of the United States machines. To Mendenhall that was the last straw. Those fellows' dynamos couldn't be worth much if such elaborate devices were necessary to support them.

The tests were made in due time. Everybody wanted to see Thomson win, most of all Rohrer, who had fallen completely under his spell. Nevertheless, every machine there got a thoroughly fair trial. Mendenhall was aware of his responsibility to the engineering art. A show of favoritism, besides being unethical, would have brought no advantage to anyone. In fact, because he believed the Thomson machine was all its inventor claimed, he tried in every way to make the tests severe, so that its superiority would be established on solid ground.

When the awards were finally made they went to Edison for his incandescent dynamo and to Thomson for his arc-light machine. The Professor received two citations:

"Premium No. 1417. System of Arc Lighting; for Intrinsic Merit and Superior Excellence in: Highest Total Efficiency, Construction and Steadiness of Lamp, and Control of System."

"Premium Special. Gold Medal for Arc Lamp; for Efficiency and Regularity of Action."

Thomson returned to New Britain a happy man. A great battle had been won. This was the first appearance of the three-coil dynamo and lights outside of the east. Now that the Thomson-Houston system had won official acclaim far from home it would become nationally known. And in Mendenhall he had won a lifelong friend.

Professor Mendenhall's judgment of the United States Lighting men had been accurate. Immediately they raised an objection to the awards, saying that the methods of electrical measurement had been at fault. Then they haled the professor into court and sued him for $50,000. Mendenhall stood trial without fear. The meters he had used had been specially imported from England for the tests. They were Sir William Thomson's latest "graded instruments," making their debut in the New World.

The judge, sizing up the parties before the bar, quickly threw the case out.

3

It was not Thomas Edison's plan to let his competitors get ahead of him. For the past year he had been making lighting history at such a rate that all other electrical news was pushed into second place.

On September 4, 1882, after working a year almost literally day and night, he had opened the first central power station for incandescent lighting in America—in an old brick building on Pearl Street in New York. It had required Edison's own peculiar brand of courage to invade the metropolis against the powerful opposition of the gas companies and the arc-light interests, stealing customers from them by offering free electricity, and wheedling permission to tear up the streets from capricious Tammany politicians. More than once an accident had sent the newspapers off into tirades of derision and abuse.

The very first day that Edison tried to connect two dynamos in parallel they got to "hunting" or seesawing and ran away with their steam engine. "Hell broke loose"; when the engine reached a thousand revolutions per minute parts began to fly off and the floor started to buckle. Everyone but Edison and Johnson, his general manager, fled. They cut the steam off just in time to prevent the walls collapsing and so saved the station. But the inventor was not dismayed. He thought up a scheme for a governor to hold the engine down and installed it that night. It didn't work. So he tried various other things and finally found a temporary solution that would suffice till the engine makers could solve the difficulty for good.

Although the station operated perfectly thereafter, it was

predicted that Edison light would wreck the city. This impression was heightened by the instant electrocution of a team of horses when they stepped on an exposed wire in a downtown street. But Edison paid no attention to his critics. He was riding full tilt into every obstacle as it came, perfectly confident that he could force the city to accept the electric lamp and learn to like it. He was showing the same furious drive now that had caused a young British employee of the Edison Telephone Company in London to remark, "These Americans are crazy. They insist on being slave-driven with genuine American oaths; they work with ferocious energy out of all proportion to the actual results achieved." A piece of invective worthy of George Bernard Shaw himself—and with good reason, for it was Shaw who said it, upon being invited to remove himself from Edison's employ.

By Christmas, 1882, five thousand incandescents were burning in the office buildings around Wall Street, although Edison had stopped giving the current away free. The securities of the gas-light companies were going down like lead on the Stock Exchange, while the Edison Electric Light Company shares rose from $100 to $3,500 in three months. Nor did it do the incandescent light any harm when a lineman for an arc-light company was killed on a pole in front of City Hall and dangled there till he had been burned black. The dramatization was complete when an alms box was nailed to the pole to receive pennies for the victim's family. Fortunately the installation was not of the Thomson-Houston make.

It had reached the point where electricians were abusing each other for not having invented the Edison system long before. An English colleague scolded Sir William Thomson for failing to devise the three-wire feeder system himself. "How could anyone have missed so obvious and simple a thing as that?" he cried.

"The only answer I can think of," Sir William drily replied, "is that no one else is Edison."

Professor Thomson's company was drawn with the rest into the Battle of the Electric Lights which Edison was so vigorously opening. Everywhere that the arc-light salesmen went they found that the incandescent people had preceded them. The year 1883 was turning into a triumphal march for Edison. One after another, small cities and even isolated towns and villages were incor-

porating Edison Electric Light companies and installing "long-waisted Mary Anns" and underground feeder systems. In the fall Thomson himself attended the opening of the first important Edison central station in New England—at Brockton, Mass.—and was forced to confess that the incandescent light was going to give dangerous competition.

But the prospect of a stiff fight did not dismay the Lynn syndicate in the least. In September the new factory was ready, and the move from Connecticut was promptly made. The new management was a far different proposition from the New Britain group, who had been afraid to take any risk. Pevear was the new president, Barton vice-president, and Coffin general manager. Main offices were immediately opened in Boston and branches established in various large cities over the country. Coffin was determined that if Edison wanted a fight he should have it.

The Lynn factory was a large three-story building with a full-sized basement—four floors available for turning out nothing but Thomson products. It was so large, in fact, that Pevear thought he would use the third floor to dry skins for his leather business. But he never did. Thomson had no sooner moved in than things began to hum. Before winter every available inch of the factory was in use, and the Professor had already given up his private experimental corner to the testing department. There was talk of building a second factory.

From the first the moving spirit in the venture was Charles A. Coffin. Sensing the coming battle with the Edison forces he realized the necessity of building up a strong commercial organization at once. So he gradually abandoned the shoe trade altogether and established himself as the pioneer electrical business specialist in America. The result of his aggressive policy was amazing. In January, 1883, only five Thomson-Houston arc-lighting installations were in operation in the entire country—all of them on private premises. A year later there were thirty-one, still all private. But in six years more the company had absorbed Brush and most of its other competitors and was the principal challenger of Edison the champion. Its stations, public and private, reached around the globe.

Soon after that Edison himself succumbed, and the patents that had made him and his rival, Thomson, the foremost

in their field, were combined under the ownership of General Electric.

There was no one left outside the fold now but George Westinghouse, who was brilliantly building an electrical giant of his own. And even he was nearly wiped out in the panic of 1893.

Coffin was without question the business genius who brought the electrical industry out of chaos. As the founder of a trust he was a bitterly criticized man—hated by such stock manipulators as Tom Lawson and Jay Gould, who tried again and again to ruin his company in Wall Street but always failed. And hated, too, by the zealots who could not or would not understand that American technology was too vast a thing to be advanced by a conglomeration of little businesses forever at each other's throats. Studying Thomson, Coffin realized that the scientist, to be productive, must be serene; that in the widening struggle for supremacy over nature no combination of skills could be too large, no degree of cooperation too great. It was thus that, as 1884 began, Coffin established the policy of backing Thomson in every idea that he had, telling him always to "go ahead, never mind the expense," asking only that he continue to invent and to improve a product already the best in the field.

The combination of Coffin and Thomson, backed by the type of assistant who naturally gravitated to them, was the principal agency which put the company ahead of its rivals. Many concerns had one genius; none outside of Lynn had two.

It became apparent to Professor Thomson's group early in 1884 that the incandescent lamp could no longer be ignored. Arc lights were unbeatable outdoors and in large halls; they were nearly worthless for ordinary indoor illumination. All around them Edison lights were driving darkness out of homes and offices and even theaters, as people suddenly seized upon electricity as the benefactor of mankind. Something must be done to meet the competition.

In Cleveland, Brush was bowing to the threat of the incandescents in the same way. He had already purchased the American rights to the English Swan lamp and was hurrying into the market with a novel combination of arc light and filament lamp, the latter operated by a lead-plate storage battery which he had

invented. The battery was switched into the arc-light circuit in the daytime for charging, then disconnected and used for lighting the incandescents at night.

Thomson gave the system a careful scrutiny and replied to it with a simpler idea. In place of the storage battery he devised a "distributor box" which allowed the incandescent lamps to burn in groups of eight directly on the arc-light mains, each group being the equivalent of a single arc. The distributor automatically switched resistance coils in and out of the circuit to compensate for lamps that might be turned off or on.

It was an ingenious scheme but the Professor regarded it only as a temporary expedient, necessary to hold Brush in line. In a short time he had designed and built a dynamo to operate incandescent lights exclusively. By 1885 the company was marching out to meet Edison on his own ground.

To compete with him at all, of course, it was necessary to have an incandescent lamp protected by independent patents. Thomson-Houston could not afford to sell dynamos to be used with lamps made by Edison, for the lamp business was bound to become the money-maker of the combination. Thus they were forced to produce an equally satisfactory incandescent of their own. Luck was with them in 1885. Two inventors named Sawyer and Man offered to license the Lynn people to make a lamp they had patented and which they claimed was older than Edison's. It was a good lamp, in some respects better than his. So the Professor took the Sawyer-Man contention at its face value, and the deal was completed. Lynn began at once to make lamps.

Unquestionably Edison had patented the only incandescent lamp principle that would work, that is, the combination of a high-resistance "filament" of carbonized material hermetically sealed into a glass globe containing the best obtainable vacuum. But there was room for legitimate doubt that Edison had been the first to disclose the discovery. A score of inventors had tried to get light by the principle of electrical resistance, and many had succeeded before Edison. The Sawyer-Man lamps dated back into the sixties; Moses Farmer had constructed a platinum-wire lamp still earlier. So had Sir William Thomson and two or three other Englishmen, including Swan. So indeed had Hiram Maxim, who later invented the machine gun. Thus it was a fair

assumption that no one had exclusive rights to the basic incandescent design.

Believing himself ethically in the clear Thomson began the manufacture of incandescents which were to all intents identical with Edison's except that they were protected by the patents of Sawyer and Man. In this he was guided somewhat by a change of heart which had suddenly overtaken the Federal courts at this time. The old tendency to favor the inventor against his infringers had abruptly disappeared. Now the judges had taken to disallowing every claim, on the theory that there was nothing new under the sun.

This severe attitude may have had the purpose of loosening up the strangling effect which patents were having in the new electrical industry. At any rate, manufacturers everywhere took it as an invitation to infringe blindly, without thought that some day the judicial heart might harden again. The result was that every electric company in America jumped the Edison claims, Thomson-Houston in the lead.

From the first the Lynn company succeeded. The Professor had added improvements which made the lamp essentially his own. Judging that the three basic elements—filament, globe, and vacuum—were common property he had searched for better methods of manufacture and ways to increase lamp life—and had found both. In this field the Lynn company soon outdistanced all competitors with a "flashing" process, using a charge of gasoline in the lamp bulbs which was burned to form a coating of graphite on the filament. This gave the slender thread greater strength and far longer life, and produced a more brilliant light.

Thus began the historic Battle of Light in which American electrical engineering was born and which was in large measure responsible for the rapid advance of the art in the decade of the eighties. It was neither short nor immediately decisive. Year after year the Edison group chose to ignore its infringers, preferring to hold its lead by aggressive commercial means. And year by year the number of the contending patents increased, while the tangle of unmolested claims grew luxuriantly and covered up the explosive foundations of the situation.

But for a long time no one heeded the signs of the gathering storm.

Chapter 14

I

The world of 1884 was treating Elihu Thomson exceptionally well; it seemed as if his every ambition was to be realized. He and Rice and a growing staff of young assistants were working the same long hours as before—even longer, in fact, for now they regularly went to the factory on Sundays too. The more they progressed the more work there was to do as the vast problems of electrical application came up over the horizon. Not one of them but would have stayed on the job around the clock if he could have done without sleep entirely.

The Professor and his men lived in a small hotel called the Boscobel, a few blocks from the plant. Here boisterous sessions continued late into the night with constant heated arguments over the right and wrong of one electrical principle or another. To and from the Boscobel they walked, morning and night, discussing and contending in eager voices which were hushed only when the Professor settled a controversy with a quiet exposition of fact or opinion. It was a happy time and a rare opportunity for youth.

Yet the Professor felt a little lonely. He had been writing long letters to Mary Louise Peck—whom he now affectionately called "Minnie." They were letters full of self-confidence and the joy of creation, but that indicated how much he needed a woman's care. They were tender letters but circumspect. The Professor was not one to ignore the conventions. He signed them all, "Your loving Elihu Thomson." And she had been answering in her neat sloping hand, quiet, cheerful, self-contained, assuring him that they could be married soon.

In the spring of 1884 the time finally arrived; the Peck family had signified their consent and the date was set.

No record is left of the wedding itself. But it was a simple affair held in the house of the bride on the first day of May. Elihu's mother came up from Philadelphia to "meet her new family" but

not to weep. She was charmed with Louise and more delighted than she could express that her famous son was getting somebody to take proper care of him at last. It was a happy time on all sides, for the Pecks were as complimented as the Thomsons were satisfied.

Mrs. Peck, who was the strictest sort of Congregationalist, was particularly delighted. She told the groom she was glad he belonged to the family now, because she could start "converting him to Christianity."

Elihu was much amused, and wagered her that she never would. He won; she never did. Every time he visited New Britain Mrs. Peck would go for him on the subject of attending church. But nothing she could say would induce the Professor to do it. Church, he said, was a place where you had to listen to a lot of things you disagreed with, told you by a man you couldn't talk back to.

Small sister-in-law Carol used to eavesdrop on these arguments and once heard Elihu ask her mother if she believed everything she read in the Bible.

"I certainly do! Every word!" the irate lady cried.

"And that," said Carol afterward, "finished religion for him."

It also shocked Mrs. Peck beyond recovery. She told Elihu point-blank that he was a hopelessly prejudiced man.

So he was—prejudiced against dogma and rigid thought wherever he found them, demanding always the right to think for himself and to express his conclusions without hindrance. Unlike Faraday he was in this, for Faraday was a blindly devoted churchman. "When Faraday opened the door to his oratory," said Tyndall, "he closed that of his laboratory."

Elihu Thomson's laboratory was never closed. Rare even among scientists was his unswerving devotion to the logic of nature. His loyalty to God as the Creator was the mainspring of his life, and he resented the attempt of formal religion to gain credit for introducing God to man.

The honeymoon was meant to be an idyll in the mountains, but it failed. They went to the Catskills for a week and were shriveled by an unseasonable spell of rain and chill. Elihu made no secret of his urgent desire to get back home to work. And so they gave up

after a few walks in the drenched woods, and traveled to Lynn, where the young bride set herself to the very considerable task of being the wife of a famous man.

2

In the early fall of 1884 an important scientific event took the Professor and his bride to Philadelphia. The Franklin Institute was holding the first all-electrical exhibition in the United States. It was to be a milestone of international significance, for the leading scientists of Europe and America were scheduled to be present to form the New World's first congress of electrical technicians. Thomson, as a young, aggressive member of the institute, was bound to take an important part in the proceedings.

The exhibition lasted for more than a month and was the first in the country to draw complete representation from the warring commercial factions. All the rivals were there, for none dared to ignore the opportunity of receiving the endorsement of the great scientists. Brush, Wood, Weston, Sprague, Edison, Thomson, and many others crowded each other for space to show their electric-lighting equipment and other apparatus. Especially active was Edison. He had always been a good showman. Now his exhibit outdid them all for the size and amount of the apparatus on hand. Moreover, he himself was present constantly, always in evidence, to the delight of the crowds, always accompanied by some one of the famous scientists.

The Professor could not resist a feeling of personal triumph as he thought of the contrast between this grand show and the little exhibition of 1874, with its primitive instruments and its lack of electric power apparatus of any kind. What a mighty change had come in those ten years! And what a tremendous advance in his own fortunes! Then he had been a youth barely of voting age, proud to serve the institute as a judge of awards for machines that were frankly curiosities. Now, a decade later, determined Americans everywhere were fighting for the chance to exploit those same curiosities and put them to work for millions all over the world.

The dynamo, which had then been labeled a hopeless second to the chemical battery by Sir William Thomson, was now unquestioned king of the world of illumination. But that was not all. Frank Sprague, who had begun as an Edison man, was here on his

own, exhibiting a group of six electric motors for use in driving all sorts of machinery and even proposed for "horseless cars." To men like Thomson, who could see ahead, the motor was the most significant thing present. He had often predicted that as soon as power could be transmitted at will over wires there would be an immense industrial advance. The exhibition proved that the time was at hand.

In Philadelphia the Professor had the time of his life. He had come back to his old home a celebrity; all his former friends flocked around him with renewed affection and respect. Better than that, he was accepted as an official spokesman for America in the councils of the scientific congress which met under Franklin Institute auspices. It was indeed an august gathering. Led by Sir William Thomson, it included such famous British lights as Sir William Preece, Lord Rayleigh, Professor Silvanus P. Thompson and Professor William Ayrton. The American side was represented by Henry A. Rowland, Simon Newcomb, J. Willard Gibbs, T. C. Mendenhall, and John Trowbridge—the backbone of scientific thought. All these men except the last were of an older generation than Elihu Thomson, yet they put his judgment on a par with their own.

He was especially delighted to meet Sir William Thomson, whom he had admired since childhood. Here he was, swapping witty remarks and talking shop as if there were not half a lifetime of experience to separate them. A warm friendship sprang up between them which lasted for many years. After Sir William had become Lord Kelvin at the hand of Victoria in 1892, he made several more trips to America. It was always Thomson whom he delighted most to see. On one occasion an admirer of both said to Kelvin, "I congratulate you, sir, on having so distinguished a son as Elihu Thomson."

"I only wish," Kelvin replied, "that he were my son."

An even closer bond was established between the Professor and Silvanus Thompson. The latter had just written the world's first textbook on electrical machinery, in which he had mentioned Elihu Thomson's dynamo as "a remarkable machine—its spherical armature is unique among armatures; its cup-shaped field magnets are unique among field magnets; its three-part commutator is unique among commutators." And the friendship which ripened

out of this meeting in 1884 became equally unique among friendships between technical men. Silvanus, the distinguished biographer of Faraday and later of Kelvin, clung to Elihu Thomson through the coming years as an exponent of integrity and common sense in the disintegrating world of the war. His pathetic letters continued to cry out to the younger man over the insanities of power-mad rulers until he died of overwork and a broken heart in 1916.

Ayrton, too, got to know Thomson well in Philadelphia and to love him in his turn. It was he more than any other Englishman who eventually brought about the presentation of the three great British awards—the Kelvin, Faraday, and Hughes medals—to this American who had become the dean of electrical engineering.

The assembled scientists organized their electrical congress as a body which was to meet from time to time at similar exhibitions, wherever they might occur. Its purpose was to be the establishment of international units of measurement in the new electrical field. For years Sir William Thomson had urged the importance of measurement to all science. Upon assuming the presidency of the British Association in 1871 he had said:

> Accurate and minute measurement seems to non-scientific imaginations a less lofty and dignified work than looking for something new. But nearly all the grandest discoveries of science have been but the rewards of accurate measurement and patient, long-continued labor in the minute sifting of results. For consider Newton and the theory of gravity; Faraday and the law of specific inductive capacity; Joule, the laws of thermodynamics; Gauss and Weber, the absolute system of electric and magnetic measurements; and Maxwell the velocity of electro-magnetic propagation.

Measurement was knowledge; without universal agreement as to the meaning of quantities there could be no general advance.

A start in this direction had been made in London in 1862 by the so-called "C.G.S. Committee," which had established the centimeter-gram-second system of measurement as the international language of physics and engineering. Maxwell, Sir William Thomson, and Siemens were the moving spirits in this, and

Professor Thomson lecturing at the Franklin Institute, Philadelphia

now Sir William had come to extend the work into the electrical field in America.

No less important was world-wide agreement on scientific units than the similar unification of monetary systems through exchange. The great purpose of the movement was to cut through the confusions of race and creed and geographical separation and make science the one common ground upon which men could meet everywhere and maintain intercourse as equals. The work done at Philadelphia was so fruitful that the occasional congresses were made permanent under the title of the International Electrotechnical Commission, of which Elihu Thomson was at one time the head. In this new guise scientific delegates from all over the world received the whole responsibility for writing a universal language—a kind of scientific Esperanto—which should bind all technical men together forever.

The start of this great undertaking in 1884 made the Franklin Institute exhibition a permanent milestone in scientific advance. An important achievement of the congress was the final choice of the "ampere" as the world-wide unit of electric current, as had been suggested at a meeting in Paris in 1881. The volt and ohm had already been agreed upon as the units of pressure and resistance. The addition of the ampere, with the exact definitions of its magnitude, erected the three basic electrical quantities as monuments to the men who had done most to make electrical engineering possible. Faraday, Henry, Coulomb, and Watt were others who later received honors of the same kind by international agreement. This action of the scientists stands as an example to the world of what can be done when men meet for the unselfish purpose of benefiting all mankind.

One interesting offshoot of this first congress was an address given by Thomson's old colleague, Professor Monroe B. Snyder, in which he pleaded for the establishing of a "National Bureau of Physical Standards" in Washington. The membership enthusiastically approved, but the suggestion fell on barren ground in the capital. Snyder fought for twenty-six years before Congress finally discerned the wisdom of the plan and established the Bureau of Standards. He himself received no credit till Elihu Thomson reminded the world long after of the Franklin Institute speech of 1884.

A more immediately fruitful effort in Philadelphia was the beginning of the American Institute of Electrical Engineers, with Thomson a founder and leading spirit. Thus the exposition had done far more than make a public showing of achievements to date. It was the fertile ground in which seeds had been planted that were to grow to great things.

3

For the first time Elihu Thomson had sat in council with the mighty and had emerged as a leader of thought among them—not a leader in the ordinary sense that he bossed and arranged and manipulated; his leadership was inspirational; men looked up to him for what he was, personally—not for what he had done or would do, but for the extraordinary balance of his mind, the subtle, invisible yet iron sinews of his integrity and judgment.

At this meeting he had ceased to be merely a rival of Edison and had become his superior. For while every man in Philadelphia had admired the spectacular young creator of the phonograph and the electric light and had sought his dynamic advice to many new problems, all had admitted that he was an inventor, purely, not an engineer. Elihu Thomson, quiet, retiring, saying very little, had proved that he was both, and a philosopher besides.

The Professor had no sooner returned from this triumph than he resumed his office as the inventive head of the powerful young company he had founded. What he had seen at the exposition had convinced him that it was high time for Thomson-Houston to broaden out from the restricted field of electric lighting into the nearly unlimited one of electric power. His first task, then, was to design a direct-current motor to compete with the machine Sprague had exhibited with such effect. Charles Coffin backed him to the limit in this, and within a year the motor was on the market, a new element very much to be reckoned with.

The work at the West Lynn factory now became an energetic assault upon many fronts at once. Though the dynamo and light remained the backbone of commercial success, the electric motor was the new infant prodigy. And while this was still squalling with babyhood ills, still greater inventions were taking physical shape under the Professor's hand. Into the next five years were to be crowded electric welding, the alternating-current distribution

system, the trolley car, and the electric meter—each one a major achievement upon which whole industries would be founded.

From the first it had been Coffin's policy to surround Thomson with the best assistants that could be found. One by one they came, gathered in from competitors or from the college science courses, the cream of the crop.

The college men, who were immediately christened "experts" and put to work testing finished machines, were paid only $5.90 a week. The skilled artisans, many of them inherited from small concerns which Coffin bought outright, received the same wages they had before. In this building of a new industry there was no time for mollycoddling, no lack of freedom of choice. A man went, not where he could get the best pay, but where he could get the best opportunity. Every worker, whether at desk or drawing board or lathe, was a pioneer and knew it. He expected to sacrifice accordingly.

The drama of these vivid years—the most productive in Thomson's life—was the result of his tremendous mental energy and the affectionate zeal of the young men whom he inspired. The scene of the action was the "model room" or experimental laboratory in a second-floor corner of the factory. Here, under the skilled fingers of a mechanic named Robert Shand, one after another of the great inventions grew to maturity. Here, one eager young disciple after another responded to the urge of the Professor's imagination and produced ideas and suggestions, sometimes inventions of his own.

Wilbur Rice had been the charter member of this group at New Britain. By the time they had reached Lynn he was working side by side with Thomson and taking out joint patents with him. One of his most important contributions illustrated the absurd competitive situation and the Professor's gently humorous approach to it.

The invention was a new style of regulator for dynamos—not for Thomson dynamos but for the rival Brush machines.

One day the Professor told Rice he supposed Brush was up against it. Without a regulator his arc-light system was decidedly inferior in performance, which of course must be worrying him a good deal. What would he be likely to do? Obviously, he would try to invent his way around the Thomson regulator without infringing it. But how?

"Now your job," the Professor told Rice, "is to take a Brush machine and see how you would regulate it if you were Brush."

Rice tackled the problem joyfully and in due time hit upon a good sound solution. Thomson was much pleased. A model was built and found to work on any dynamo, Brush or otherwise. "Let us patent this at once," the Professor decided, "and see what happens."

The specifications were drawn and the claims filed; in due course the patent was issued. It caught Brush entirely unprepared, for the Thomson-Rice regulator proved to contain the only practical method of controlling Brush dynamos. The result was that the Cleveland company had to choose between litigation and no regulator at all. It took the latter. When its business was bought by the Lynn concern Thomson brought out the Rice regulator and installed it on all Brush machines. Results were so satisfactory that the once-competing dynamo was built and sold for years, bearing the Thomson-Houston nameplate.

This was, of course, only one skirmish in the rough-and-tumble patent fight. In another encounter Brush was the winner, with a double-carbon arc lamp that burned all night without attention. The patents on it were a constant source of restraint upon Thomson, and he never completely got around them, though he never ceased to try.

As the Lynn venture grew, E. W. Rice began to show exceptional talent for administration as well as invention. Presently he was made factory manager in charge of all production work in the company, and his intimate association with the Professor came to an end. He had married Kate Doen a month after his chief's wedding and was now settled in Lynn as an officer and guiding light of the company. At twenty-three his path was headed upward; he would climb steadily till he became board chairman of General Electric and one of the great industrial organizers of his day. But never in his life would he cease to honor "his Professor" or fail to come to him for help when problems got too difficult.

A steady succession of energetic young men followed Rice's path through the model room. The first of these was Albert Rohrer, who had fallen in love with the Professor at Cincinnati in 1883. The following spring he applied to the company for a job—any job that would put him in the midst of electrical pioneering. By return

mail he was accepted, and in 1884 came to work in Lynn as an "expert" at the exceptional salary of $12.50 a week. Nominally he was hired to test the new machines. But Thomson remembered his zeal in Cincinnati the year before and took him under his wing in the model room.

"I would have an idea," said Rohrer, looking back. "The Professor would listen to it and immediately point out how it infringed somebody else's patent. Then he would say, 'I think we may be able to dodge them this way.' Pulling an old envelope from his pocket he would rapidly sketch the arrangement he thought would work. 'Now go and make one and we shall see,' he would finish, and turn at once to something else."

Rohrer worked diligently, coming back to the factory evenings and on Sundays. Many a time he would knock on Thomson's office door and be admitted, to sit for hours with the Professor and Wilbur Rice discussing new devices—switches, lightning arresters, transformers, generators, trolley-car apparatus. He was full of practical ideas, many of which Thomson translated into patentable improvements. But he was not himself an inventor; his talent was for getting things done. Soon he was singled out as the factory "production man." In this capacity he began traveling about as installation engineer and trouble shooter.

During Rohrer's close association with the Professor the competitive struggle between electrical rivals moved into a new phase, which has been called the Battle of the Currents. The early development of electric power had been done entirely with direct currents, flowing in one direction around a circuit to light lamps or turn electric motors. Alternating current, which reversed itself many times every second, had been abandoned when the commutator was invented and had received scant attention since.

But the neglect was only temporary. Electricians knew that alternating current had possibilities that should be looked into. No one realized this better than Edison, who had committed himself completely to direct-current power and was, by 1885, the foremost maker of dynamos and lighting systems operating on the direct-current principle. Edison's opposition to alternating current amounted to an obsession. Vigorously he denied its possibilities and contended hotly that it was inefficient and dangerous.

Professor Thomson had no such prejudice. Since inventing his three-coil dynamo in 1875 he had argued steadily that alternating-current distribution of power was the only efficient method. Instead of driving large currents through heavy copper mains as Edison did, he proposed raising the voltage by means of induction coils, or "transformers," and sending correspondingly small currents through small wires. At the receiving end, the voltage could be "stepped down" again, and the currents magnified for local service. Thus he believed that great power could be sent over distances of many miles without appreciable resistance losses or heavy outlay for copper wire.

As soon as the Lynn factory was on its feet he had begun experimenting with this new system. Late in 1886 a small alternator and transformers were built for a test installation of incandescent lamps. Thomson knew that if "a-c" power could be applied to indoor lighting the great advantage which the Edison systems had could be nullified. Edison's "three-mile limit" was sure to be his undoing.

To test out the plan "Factory B," just then being added to the plant, was completely lighted with alternating current transmitted from Factory A next door. It worked perfectly.

The secret of this success was the transformer, which Thomson had devised to alter voltage and current at the ends of the line. This was not simply an induction coil but a closed iron ring with two windings upon it, designed for high efficiency and self-regulation. He had patented the arrangement in 1878, putting it aside till there should be time to apply it. He had realized then that in all likelihood someone else would follow suit and beat him to the commercial application. The transformer principle was then fifty-five years old, having been discovered by Faraday and Henry.

Thomson's fears of competition were partly justified. In Europe, two inventors, Gaulard and Gibbs, had patented transformer designs which were good. These patents had recently been bought by young George Westinghouse of Pittsburgh, who believed in alternating-current power and intended to establish a business upon it. So at the time when Thomson's interest was reviving a new commercial rival awaited him. Westinghouse had hired brilliant young William Stanley, a Massachusetts inventor,

who was already at work improving the Gaulard-Gibbs designs and patenting everything he could devise a claim for.

The year 1886 opened with the principal electrical contenders arranged in a triangle: Westinghouse and Stanley in one corner, Thomson in the second, and Edison growling at all of them from the third. Stanley got the jump on them all that spring by building a line a mile long from his workshop into the town of Great Barrington, Mass., and transmitting alternating currents over it to operate lights. This was the first commercial application on record, as well as the longest transmission ever attempted. It was so successful that Westinghouse immediately started commercial exploitation on a scale to compete with Edison and Thomson.

It was simple enough for the Lynn company to jump into the competition and snatch the lead from Westinghouse, for Thomson understood the principles better than any of them. But to the surprise and annoyance of everyone, the Professor refused to allow it. He believed that alternating current was still too dangerous for public use. Efficient transmission required voltages of three thousand or more—a deadly pressure which would kill on contact.

Normally this voltage would be confined to the "high sides" of the transformers and well out of reach. But suppose a transformer got short-circuited. Then a customer might reach up to turn on a light in his home and become part of the high-tension circuit. If he happened to ground himself on a water pipe at the same time, and in *addition*, if some distant part of the power system was also grounded, then a fatal shock might result. An unlikely chain of coincidence, Thomson admitted, but a risk too great to fasten upon an unsuspecting public. So long as deadly shocks were possible at all, he would not allow the company to sell the new apparatus. Instead, he set to work to find safeguards that would be infallible.

It was a courageous position to take. Rice, Rohrer, and all the Professor's close associates understood and honored him for it. And Charles Coffin approved. But the company's business group were uneasy. They saw their rivals hurrying ahead without scruple, intent upon cornering the market. Westinghouse in particular was making progress and was already becoming a formidable rival to Edison and direct current.

For more than a year Thomson stoutly clung to his position and continued to experiment on safety devices. He and Coffin had many conferences about it and agreed that this might be very good business strategy. Westinghouse was drawing violent fire from the Edison camp on the ground that alternating currents were deadly. There was enough truth in the contention to hold the Pittsburgh firm back and use up much of its time and money in making counterclaims. This interval could safely be used to solve the protection problem permanently. Then, when the safety device was invented, Thomson-Houston could come out with it, answer all Edison's objections, and outdistance Westinghouse before that firm could recover from its surprise.

The Edison interests were proceeding in a thoroughly intemperate manner, publishing vicious attacks in newspapers and magazines against everyone connected with the alternating-current art. Thomas Edison had even taken up the cudgels himself. Years later a story became current that he had bought out a small machine shop and, finding it running with alternating current, had fired the manager, ripped out the offending system, and put in a direct-current one of his own.

In a booklet bound in a scarlet cover, and titled "A Warning from the Edison Electric Light Company," the direct-current interests brought a wholesale indictment against competitors, accusing them of patent theft, fraud, and dishonest financing. Toward the end, under the heading of "Caution 4," the booklet expanded upon the theme of danger in these fantastic words:

> It is clear that high (electrical) pressure, particularly if accompanied by rapid alternations, is not destined to assume any permanent position. It would be legislated out of existence in a very brief period even if it did not previously die a natural death.

A little further on it spoke witheringly of George Westinghouse as

> . . . the inventor of the vaunted system of distribution which is today recognized by every thoroughly-read electrician as only an *ignis fatuus*, in following which the Pittsburgh company have at every step sunk deeper in the quagmire of disappointment.

In the Appendix were alleged examples of what happened to unfortunates who got in contact with alternating-current wires and were cremated or shocked to death. Entirely ignored was the fact, also known to every "thoroughly-read electrician," that direct current, volt for volt, was just as deadly as alternating. Edison's only real claim was that his system was operated entirely at low pressure.

I

Chapter 15

After a year's thought and experiment Professor Thomson discovered two ways to prevent dangerous shocks from alternating currents. The better of the two was the absurdly simple expedient of connecting the secondary transformer windings by heavy wires to ground. This completely eliminated the danger of high voltages charging the wires inside buildings, for if a transformer's insulation failed the current would pass directly to earth.

It was an occasion of rejoicing throughout the company when the Professor announced his invention and withdrew his objection to the alternating-current system. With the utmost dispatch designs were finished and production of dynamos and transformers begun. The Thomson-Houston Company was presently the leader in the field; before long it lifted from Westinghouse the burden of driving Edison's system entirely out of business.

Direct-current distribution failed, as the Professor had long predicted it would, because it was uneconomical. As Edison customers multiplied, the investment in copper cables and cumbersome dynamos became gigantic. Alternating-current apparatus, meanwhile, was light and efficient, and the investment in copper for transmission was very small. The comparison between the two was well shown by a case that occurred soon after the Lynn company invaded the field.

One of its first alternating-current installations was at Montpelier, Vt., where a young Thomson-Houston "expert," Charlie Burleigh, was sent to replace a direct-current lighting plant in 1887. Part of Burleigh's job was to pull up the old feeder wires of the earlier installation and put down new ones to serve the transformer system. So much less copper was required to carry the alternating currents that he came back to Lynn with a huge reel of wire left over from the change. It was found that the value of this wire was more than the entire cost of doing the job.

But the country did not abandon direct current overnight. Edison's propaganda had thrown the electric-power business into such confusion that the public went to absurd extremes. One of these was the action of the Insurance Underwriters in actually forbidding the use of the Thomson grounded secondary. They had no objection to an ungrounded transformer but professed to believe that the protection was more dangerous than the thing it cured.

The Professor serenely ignored them; he was satisfied. If the insurance companies insisted on risking people's lives, it was not his affair. He had done his part. Gradually the situation changed. After a few years the Underwriters permitted grounding; after a few more they recommended it. Finally they required it. No system today may be installed without the water-pipe connection which may be seen running from the switch box in any cellar, exactly as Professor Thomson first recommended.

In 1921 his contribution was at last recognized and he received the official title of "The Father of Protective Grounding."

Thomas Edison took his defeat hard; he did not admit it till he had fought a losing battle for several years more. One day in 1888 Albert Rohrer met a friend on the train who told him of an interesting experiment being done at Columbia University. One H. P. Brown, it seemed, was electrocuting dogs with alternating current. It was absolutely sure. It killed them every time.

Rohrer was much upset. He guessed that this "research" must be a trick of the Edison people to frighten the public, for Brown was an Edison employee. So he hurried back to Lynn and told Rice what he had heard. Rice was equally excited and was sure the company ought to take some action. He went in to see Coffin at once.

The young engineer repeated his story while the manager listened attentively. Rice urged him to publish a refutation.

"People ought to be told," he cried, "that direct current will kill a dog just as dead as alternating will!"

Coffin smiled. "Of course," he said, "we know that. But it isn't necessary to say so. Westinghouse is doing all the talking for our side, and doing it well. We are just going to keep quiet and saw wood."

It was a sage policy for the company to follow. The main battleground was the columns of the daily papers, where distortion and downright falsehood were the order of the day. Coffin knew that nothing was to be gained by entering the mud-slinging contest. While the others were busy calling names he would sell dynamos.

The Columbia experiments proved to be more than a publicity stunt, however. They were for the purpose of showing that electrocution could be used in capital punishment. That same year the state of New York adopted this means of killing its criminals, using alternating current at 2,000 volts as the lethal agent. It was a good break for Edison. Research had shown that the very same voltage that his rivals proposed for transmitting current to light homes was instantaneously fatal.

The first prisoner to be electrocuted was William Kammler, at Auburn Prison on August 6, 1890. His case was a *cause célèbre* which was argued in the newspapers and fought through the New York courts for eighteen months. It was contended that death by electricity was an inhuman punishment and therefore contrary to the Constitution. But the electrocution law was sustained in the state courts and finally in the Federal courts as well. The Edison people played both ends to the limit, emphasizing the horror angle until it was shown to be false and then changing to the instantaneous-death argument advanced by the courts.

The only reply ever made by Thomson-Houston was a succession of technical papers which the Professor contributed to various scientific journals in these years, discussing alternating current from all angles. He made no reference to the controversy whatever, beyond the mild reminder that direct current was always more deadly than alternating current at the same voltage. But he stated the facts of the whole matter so clearly and skillfully that the absurdity of the danger gradually became established. When Elihu Thomson made a statement it was accepted as fact; he was known everywhere as a man who spoke the truth if he spoke at all.

To him and to Professor Henry A. Rowland of Johns Hopkins went the full credit for destroying the alternating-current bogey. As the country's leading physicist Rowland was retained by the Niagara Power and Construction Company to decide whether the

falls should be developed by the direct- or alternating-current system. Rowland decided on the latter, in the face of strongly expressed opposition from Lord Kelvin and his associates in England. Later, the company demanded an abatement of his fee, which they claimed was exorbitant. Rowland admitted it was high but insisted it was fair on account of the vital nature of the decision he had made. He haled them into court. At the trial the company attorney tried to discredit him by asking him leading questions on the witness stand. "Professor Rowland," he demanded at one point, "whom do you consider the greatest physicist in the United States?"

"Since I am under oath to tell the truth," Rowland replied, "I must answer that *I* am."

Every expert summoned corroborated this testimony. Rowland won the case and collected his fee. In the meantime the company had taken his advice and was developing the falls with alternating current. This was fortunate, for if direct current had been chosen instead, the system would have been obsolete before it could have been put into operation. As it was, the Niagara decision had a profound influence on power development throughout the world.

Professor Thomson made no spectacular appearance in court, but his support of alternating current was equally as important as Rowland's. In 1889 he became the president of the American Institute of Electrical Engineers, at the moment when the Battle of the Currents was at its fiercest, and his influence helped to swing the tide away from Edison. The Professor never lost an opportunity to plead the case of alternating-current power. He saw that the utilization of electricity would increasingly depend on long-distance transmission, which could be done economically only by alternating-current means.

In a Boston meeting of the institute a young Columbia physics professor by the name of Michael Pupin gave a brilliant defense of alternating currents, which he visualized as the sole reliance for the future in communication as well as power. The speech caused an open split in the ranks, and Pupin was damned for "electrical heresy." But Thomson, who was at the meeting, came to his defense.

The generous act gave the young Serbian pioneer scientific

standing and launched him into a series of alternating-current experiments which led to the telephone "loading coil." This invention made Pupin famous, for it permitted the human voice to be transmitted over long cables throughout the world.

2

The intensive work on alternating-current apparatus had shown Professor Thomson what a versatile thing a transformer could be, adapting itself to extremes of voltage or current by a small change in the design of the windings. A transformer could be built, for instance, to yield hundreds, even thousands, of amperes at a few volts pressure from an ordinary lighting circuit. This suggested to him that the time had come for the development of electric welding. The element of an economical heavy-current supply that had been missing when the discovery was made in 1877 was now at hand. As soon as he had a moment to spare he set the model room to building a first small welding transformer.

The principle of electric resistance welding seems obvious. Yet in 1885 no one but Thomson had thought of it. All it required was a transformer with a primary to be connected to the lighting circuit and a secondary of a few turns of massive copper cable. The ends of this cable were fitted with strong clamps which grasped the pieces of metal to be welded and forced them tightly together. The heavy current flowing through the joint created such a high heat that the metal was melted and run together. That was—and is still—the whole principle.

"This first transformer," says the Professor, "was remarkably successful. With its currents welds were made on small rods and bars of practically all the useful metals, even the brittle ones like bismuth and antimony. The apparatus was made with the possibility of varying widely the relation of the secondary to the primary turns, as we were working in a new field and there was no knowledge of the voltage that would be required or the strength of the current that would be demanded."

Thomson understood at once the prime importance of this new tool. Although many metals were known, almost none but iron and copper could be used because of the difficulty of fabricating them into desired shapes and combinations. The new art

promised a revolution. The Professor was so excited with the possibilities that he built the next transformer himself. This, later known as the famous "Jew's-harp coil," was the usual transformer in reverse.

Its secondary consisted of a single ring made of a heavy copper bar, with the ends protruding as terminals. Many turns of fine wire were arranged concentrically to form the primary, and both were wound about with iron wire to form the magnetic circuit. It looked something like a doughnut and weighed about half a ton. It was even more successful than the first transformer. Butt welds of steel bars nearly an inch in diameter could be made with it in a few seconds.

At the close of 1886 the Professor published an account of these experiments in the *Electrical World*, and the article was copied all over the globe. The invention was probably his greatest contribution to industrial advance. He had, of course, quickly applied for a patent and was surprised to find that all his claims were granted outright, without a single reference to similar work by others. This condition did not last long, however. The inevitable claim jumpers soon began to appear.

"A certain quasi-inventor named Reiss," the Professor records, "filed a case claiming the gradual increase of current during the making of a weld—a manifest endeavor to step up behind without any experience. I at once went into the Patent Office with like claims and Reiss was beaten in his characteristic 'little game.' "

This man and another who soon followed were playing the old trick of threatening a patent with a slightly modified form of itself, hoping that the inventor would buy the challenger off. The patent business being a lawyer's game of words, this sort of fraud often worked. If the original claims were slightly ambiguous or included more than the invention could perform, a smart trickster could reword the patent and persuade the courts that it was his own. Bell had nearly lost possession of the telephone at the hands of an imposter called Drawbaugh. Other famous men fared worse.

But the Thomson welding patent came through unscathed and was soon the basis for a separate manufacturing company in Lynn. The invention did not fall within the provisions of the contract he had signed with Thomson-Houston, and after licensing them to receive welding equipment for their own use he started out on the

venture independently. This was the only invention the Professor ever retained as his own property, and it made a powerful industry in its own right. Its success stemmed directly from the strength of the patent on which it was based. The first claim, which attorneys marveled at as an example of perfect patent writing, Thomson had composed as follows:

"The herein-described art of effecting union between two pieces of metal, consisting in holding the same in contact at the point of union and simultaneously passing a current of electricity through the joint, of a power to fuse and unite the pieces, as and for the purpose described."

Gibberish to the layman, it nevertheless saved its author enormous sums in litigation and many months of time that might have been needed to defend a weaker patent. Electric resistance welding soon became a standard manufacturing process. Later, the Thomson company bought the De Meritens *arc*-welding patent, which had lain unused for several years for lack of an application and was for sale cheap. For a time they controlled all welding done with electricity. The vast importance of this art today needs no reiteration here. From the mightiest battleship and airplane down to the cheapest toy, welding of one kind or the other is the principal reliance in joining pieces of metal. It all began on that evening at the Franklin Institute when Elihu Thomson's curiosity led him to work an induction coil backward and thus produce the first electric weld.

The transformer experiments also opened the door to the vast field of alternating-current motors, by assisting Thomson in the discovery of "magnetic repulsion." Like welding, its origin was in part accidental, but its recognition and development were the products of his rare ability to appreciate at once the significance of a new principle.

The Professor was busying himself one day in the model room with a transformer having a ring-shaped iron core with a gap in it. Remembering Faraday's historic experiment with a copper disk revolving in a magnetic field, he wondered what would happen in the case of alternating current. So he put a thick plate of copper in the gap and turned the transformer on. Instantly the copper leaped out of his hand and sailed across the room. This remarkable action puzzled him for a minute; then he guessed at what must be

Elihu and Mary Louise (Peck) Thomson in their early Lynn days.

happening: currents set up in the copper by induction were reacting with the magnetic field in the gap and producing a repulsive force. But he was amazed at the strength of the force displayed.

The unanswered questions posed by this chance experiment immediately led Thomson into a long series of studies of the alternating magnetic field and its effect upon near-by conductors, especially when the latter were short-circuited. He soon found an explanation for the strong repulsion forces in the fact that the induced currents lagged behind the magnetic impulses that created them and so partly wiped out the attractive force which should have been present also. Thus for the greater part of each alternating cycle the preponderant effect was a struggle of the two elements to push each other away.

It was a most important discovery. Up to this time no mechanical forces of any magnitude had been derived from alternating currents. Now the Professor realized that it should be possible to use repulsion for converting these currents into useful power. The vista suddenly opened was tremendous. The alternating system could be spread over great distances without appreciable loss and at small expense. If motors could be devised to work on it, instead of only upon the costly direct current, a new electrical age was ahead.

Thomson dropped everything and concentrated on the design of a "repulsion" motor. Rapidly he sketched out a machine using the tendency of a short-circuited coil to run away from an alternating magnetic field to cause rotation. The model room completed a working model in a few days; it was so promising that improved designs were drawn up quickly and patents applied for. This was the first "induction motor" in the world.

The behavior of the alternating magnetic field so fascinated the Professor that he had a set of demonstration apparatus made up to show off the various effects. In May, 1887, he took this outfit to New York and lectured with it before the American Institute of Electrical Engineers. "Novel Phenomena of Alternating Currents" was the modest title, but the demonstration caused a sensation. A copper ring was thrown into the air by the pole of an alternating-current magnet; an incandescent lamp lighted when it was floated in water over the magnet; disks and spheres rotated when brought near an alternating pole "shaded"

by a heavy copper ring. With these and many other startling experiments Professor Thomson opened up an entirely new region to the engineers. The lecture was soon published and reprinted in the leading scientific journals both in America and Europe; immediately it took its place beside Thomson's welding invention as a major contribution to the art. This simple demonstration of a new electrical principle is credited with having started world interest in alternating-current power.

This interest was as far-reaching and fundamental as the revolution caused by Edison's incandescent lamp. Laboratories everywhere began experiments in the new field. Among the Professor's contributions in the next few years were the constant-current transformer and other self-regulating apparatus for street-lighting systems; the principle of oil insulation for switches and transformers; the "shaded-pole" induction motor for use in fans and other household appliances; the three-coil universal motor used in all electrical toys and many other devices today; and eventually the inclined-coil voltmeter and ammeter.

In the forefront of the alternating-current race was Westinghouse, with the "polyphase" system invented by Nikola Tesla, a young Yugoslavian who had come to America to work for Edison. Tesla was present in New York at Thomson's lecture and was so inspired by him that he abandoned Edison's direct-current work and began experimenting in the new field. Soon he had patents on a motor run by several phases of alternating current at once, upon which principle a whole new branch of the art was based.

The polyphase system was Tesla's great contribution to electrical engineering. Subsequently he went off on the dangerous tangent that lures so many brilliant inventors—that compound of genuine engineering, imaginative extravagance, and the love of public acclaim. He was, as Edison remarked, "a wonderful dreamer and most successful as his own advertising agent."

Nikola Tesla respected and admired Professor Thomson and considered he had given him his start. But this did not prevent him from accepting credit for later inventions which were clearly not his. The famous "Tesla coil," for instance, was only a spectacular form of high-frequency transformer invented, and patented, by Thomson himself.

Nevertheless, Tesla's name has always been one to conjure with in America, though his polyphase patents are the only ones not remaining in the realm of the half practical, half fantastic. All his life Tesla, endowed with a genius for attracting public attention, was a legendary figure, repeatedly credited with brilliant new ideas that were seldom heard of after their first publication. His habit of making excessive claims for credit denied him the position of true distinction to which his early work entitled him.

As the President of the Institute of Electrical Engineers, and a great American pioneer, Elihu Thomson went abroad in 1889 to represent the United States at international meetings in London and at the Exposition Universelle in Paris. His progress through England and France was a triumphal march of meetings and dinners. He had with him the repulsion apparatus which had caused such a stir in New York, and this he demonstrated with even greater effect in Europe.

His appearance at a great banquet at the Guild Hall in May was typical of his unwavering ability to charm an audience. He had sat quietly through the dinner at the speaker's table, effacing himself as was his wont. Six hundred foreign engineers were filling the hall with a buzz that all but drowned out the voice of an American delegate who had completely lost his audience.

"One of our American college professors," Thomson recalls, "passed me a note saying, 'Thomson, it is your turn next, and for the Lord's sake, get them back!' I answered his note, 'I will if I can.' The denouement was that I did get them back and had the attention of the body present in a few minutes after I began."

In eighty-three years he was never known to talk to people who did not listen.

Crossing the Channel in June with Mrs. Thomson the Professor joined up with young Albert Rohrer, now a full-fledged engineer for the Lynn company. Rohrer had been sent over to prepare the Thomson-Houston exhibit at the exposition. The Professor was in a jocular mood. The repulsion apparatus had been set up in a special booth at the exhibition and from the moment of opening drew large crowds. Once or twice Thomson appeared in person to conduct a demonstration but for the most part proceeded to enjoy himself in the Paris he had learned to love eleven years before.

As in everything he set out to do, he had prepared himself thoroughly in French and insisted on speaking the language on all occasions. It happened one day that he needed to buy some new underwear. Rohrer thought that in so delicate a matter it would be good sense to go to one of the smaller shops where "On parle Anglais" and embarrassment could be avoided. But Thomson said, "By no means, Rohrer. We shall go to the largest *magasin* we can find, and you will see what I can do."

In the ordeal that followed, Rohrer did all the suffering. The Professor, by a combination of simple French and the sign language, got his underwear; the more he upset the shopgirls the more he seemed to like it. His youthful spirit, never far beneath the surface, was having full rein. And later he made Rohrer go swimming with him in the Seine—not, however, in the new underwear but in a contraption of heavy wool, a "bathing dress" in the height of Parisian style.

During the summer the Thomsons and Rohrer traveled to Switzerland, where the Professor insisted on Alpine exploits that filled his wife with unnecessary fears. He loved to take what seemed to be wild chances but was always careful to do only what he knew he could bring off safely. After he had had his fill, back they went to Paris, to receive more honors still.

At a *déjeuner* of the electrical jury of the exposition Elihu Thomson established himself in the affections of the French. Flammarion, the celebrated astronomer, was there, and the venerable Zénobe Théophile Gramme himself, who had not appeared in public for years. Both of them came for the express purpose of meeting this famous young American scientist.

But he was not recognized only by the scientific men; later on the French government itself decorated him and made him a Chevalier et Officier de la Légion d'honneur.

This was the first of a long line of tributes accorded him by the Europeans and he treasured it highly. But another, which also came after he had returned to America, definitely placed him in the ranks of the immortals.

Professor J. A. Fleming, already prominent in British science, had seen the repulsion apparatus in Paris and now begged to be allowed to borrow it. During the winter of 1889 he demonstrated it before the Royal Institution in a lecture which made such a deep

impression that the institution asked for permanent possession of it. Thomson, not suspecting what was to come, gladly complied. A short time afterward he was amazed to learn that the institution had placed it in a cabinet alongside Faraday's original dynamo and induction coil, the most treasured scientific relics in London. There, presumably, it remains to this day.

Elihu Thomson and Michael Faraday thus shared honors for the fundamental discoveries at the root of electrical engineering.

Chapter 16

I

The first years of the Professor's marriage were so crowded with scientific adventure that he had scarcely any home life at all. Much of the excitement was caused by the almost continuous necessity of fighting patent infringements in the courts. As a bride of twelve months, Minnie Thomson rather dolefully wrote to her mother:

> I haven't had a good time since I last wrote as Elihu is having such a horrid one. He has had to strain every nerve in connection with the suit. Mr. Fish (the company attorney) kept him busy in Boston every day and left him only nights to work on his Affidavit, which was thirty-five pages of foolscap long and included a lot of drawings. A small electric machine had to be built besides, which no one knew how to do unless Elihu gave all directions.
>
> Elihu would tell me one day to have an early dinner and I would get things ready at 12:30 and then wait till nearly two before seeing him. Another day he went for the afternoon and evening and told me to expect him late in the evening. I had just finished clearing up after an early supper, had let Bessie go out and the fire too when E. appeared and wanted a hearty supper as he had had little dinner, was tired out and had got to write all the evening. He actually sat up till five in the morning writing every minute. Then rose at seven and went down to the shop and found that scarcely any of the drawings were right and the machine not done. He had to work for all he was worth till two when he appeared, hurried down his dinner, went off to Boston and sat up again till twelve after his return.
>
> That was last night. Today he is in Boston again reading to Mr. Fish and having the affidavit fixed up. The Weston company have been so mean in giving them but a week to get ready that I sincerely hope they will lose their suit. Elihu leaves for Utica tomorrow night and will be gone a day or two. So much

nervous excitement has started his teeth again, and when he left this morning his upper lip was all puffed out with a swelling from an ulcerated tooth.

I wish sometimes that Elihu was not in any such uncertain business as the Electric Light. Just as soon as it succeeds the money all flows away in litigation.

But she was a loyal wife who quickly accustomed herself to this unpredictable schedule. Presently there was a son, Stuart, to take up her time—a son who showed unmistakable signs of mathematical genius almost before he could talk. Poor Minnie was destined to have two scientists in the house.

The incessant patent suits brought by the rival companies made the Professor's life miserable and wasted weeks of his time, but they did not deter him from new ventures that seemed desirable. In 1888 the company decided that it would enter the field of the electric car. This projected the Professor into a new set of adventures and experiments. But now the usual situation was reversed; Thomson was not a pioneer in electric traction, but a latecomer who must catch up fast enough to assure his concern an equal advantage with the rest.

The early days of the electrified horse-car had been made lurid by the primitive electric motors, which were wholly inadequate for such rough service. But inventors persisted; the demand for better transportation was urgent. The horse population was on the way to swamping the cities of America. Huge stables sprawled out everywhere and property values were dropping dangerously.

Thomas Davenport built, in 1834, what was probably the first practical electric railway model and exhibited it throughout New England. This interesting relic was unfortunately lost at sea in 1900 on its way to the Paris Exposition. In 1839 Robert Davidson, a Scotchman, built a small locomotive and operated it with electric batteries on the main line of the Edinburgh-Glasgow railway. It carried two people and made 4 miles an hour.

Professor Farmer and others made various further attempts in the next thirty years but nothing important was done until Siemens ran an electric engine and three cars at the Berlin Exhibition of 1879. By this time batteries had given way to

dynamo-generated direct current and the elements for successful electric transportation were in hand.

Thomas Edison opened the attack on the problem in this country in 1880, by building an electric railway around his property in Menlo Park a third of a mile long. This he demonstrated personally to all the notables who came to see him. The rudimentary locomotive was only a flatcar with a 12-horsepower motor on it, driving the wheels through a friction pulley, held in contact by the pressure of the hand. The passengers were towed behind on another flatcar with an awning over it which Edison called the "Pullman."

The inventor loved to show off by taking the curves of his private road at top speed. As his second locomotive easily attained 40 miles an hour he frequently had accidents and frightened his visitors nearly to death. For this reason he failed to capture the interest of railroad magnates to whom he had hoped to sell his traction ideas, and so abandoned the experiment. However, Edison did build a third locomotive, "The Judge," which was operated at the Chicago Exposition of 1883 with great success. He would no doubt have done still more if the electric light had not suddenly absorbed all his time and energy.

Edison's assistant in the traction experiments was Frank Sprague. When the "Old Man" gave up the work, Sprague set out on his own to make the electric car practical. The Menlo Park railway had received so much public attention that inventors were already crowding the field and soon Sprague was engulfed in the usual patent troubles.

In those days there were no electric motors; the cars had to be driven by dynamos operating in reverse. This gave exceedingly poor results. To be of any value the electric car must start up under full load and pull itself around sharp curves and up steep hills. A special motor was needed which could stand this heavy abuse without burning up. Sprague set out to invent such a motor.

In the meantime three other men—Bentley, Knight, and Van Depoele by name—were doing the same thing in the middle west. Their success was only partial; traction motors could be designed that were powerful enough, but the problem of getting the electric current through their brushes and commutators was well-nigh insoluble. Sparks and flashes accompanied every start or reversal, and the machines rapidly burned up with the vicious overload

currents required. Since the brushes must be tinkered with continually, the motors had to be mounted inside the cars where they were accessible. An equally knotty problem lay in getting the current to the cars from the power station. People objected to "live" rails in the streets, and if the wires were submerged in slots they quickly short-circuited when it rained or snowed.

Van Depoele made the first big improvement by putting up an overhead wire and devising the underrunning trolley pole and grooved wheel, which gave the modern streetcar its familiar name. But he, too, ran into trouble. Many cities objected to electrified wires in the air because they feared these would kill the trees and menace the population by falling in a storm.

Nevertheless, electric "trams" gradually appeared in the large cities and gave a crude kind of service. Early in 1886 Frank Sprague invaded New York City to put on a demonstration, hoping to interest the Manhattan Elevated Railway, then a steam road controlled by Cyrus Field of Atlantic cable fame. Jay Gould was invited to help in the financing. But during the first ride on the overhead line a fuse blew out, startling Gould so that he nearly fell overboard into the street. He never got over the fright and refused to have anything to do with electric traction thereafter.

The Edison Light Company showed interest, however, and some money was collected to buy Sprague's patents. Then the project was suddenly dropped; Sprague never knew why. The truth probably was that the elegant metropolis required something more perfectly developed than a horse-car without the horse.

Sprague abandoned the elevated railway scheme and began a successful career making stationary electric motor installations in factories and stores, and pioneering the electric elevator. But even here trouble pursued him. Van Depoele's company was soon after him with infringement suits.

In the meantime the Bentley-Knight partnership was making moderate progress with street railways, using a converted horse-car with an early form of direct-current motor furnished by Thomson-Houston. But this motor was not equal to the hard service and gave poor results. Albert Rohrer got a good deal of his early experience traveling all over the country on trouble-shooting expeditions, trying to make these motors stand the abuse.

On the occasion of the opening of a trolley line in Woonsocket,

R. I., Knight acted as motorman while Rohrer lay flat on the floor of the car and manipulated the brush mechanism of the motor through a trap door. In this exhausting position he figured out a setting for the brushes which cut the sparking down to a minimum. He rushed back to the factory that night to persuade Thomson to change the design so that the motors would run without an attendant lying on the floor of the car. The change was soon made and Rohrer went back to the customer and put his invention into practice.

The Woonsocket line became a spectacular success—with one car running. The first day it was open for public business it carried a "curiosity load" of eleven hundred people, operating steadily for thirteen hours. Rohrer and Knight rode on the platform with their fingers crossed. The motor was running much too well.

In a few weeks Knight had five more cars in service; Woonsocket felt very proud. But it was not to be for long. A few months later all five were out of service at once. The motor commutators were chewed to pieces with the constant sparking that could not be stopped. Allegheny City, Pa., had eight cars with six out of service.

The prospects for the trolley car looked very poor indeed until someone should invent a new kind of motor that did not burn itself up.

2

When Thomson-Houston entered the traction business in 1888 the promise of success seemed very remote. There had just been a convention of street-railway executives at which a talk on trolley cars had been booed, and the speaker had been asked to surrender his time to a discussion of the care and feeding of the horse. Eight years of experiment throughout the country had shown that electric traction could work if only a cure could be found for the sparking of the motors. But there appeared to be little hope of such a cure. Alternating-current motors were unable to offer any help, for they could not start up under load. Traction service demanded a supermotor run by direct current with none of direct current's shortcomings.

The Lynn company took the plunge because Professor Thom-

son believed that eventually such a motor could be made. It was better, he thought, to struggle along side by side with the other concerns than to remain aloof and be left out when the crucial invention came. If the company began building trolley cars of its own it was quite likely that the solution would be found in Lynn itself.

But Charles Coffin decided differently. Rohrer's short experience was their only asset in the new field; it would avoid mistakes and save much time if the company picked out the most promising trolley-car experimenter in the country and bought his business outright. So he asked Thomson which one of the traction men he considered the best. Without hesitation the Professor named Van Depoele. To his mind this inventor, though he had scored the least commercial success of any contestant, was the most original. "Of course," he told Coffin, "his value lies principally in the future. At the moment his back is a little tired carrying so many lawsuits."

Coffin accepted the choice without question. Very soon Van Depoele himself was on his way to Lynn for a conference.

Charles J. Van Depoele was a Belgian who had spent his youth apprenticed to a wood carver in France and finally migrated to America to set up in that trade for himself. He had been swept into the gold rush of the electric light in 1880 when every young man who was good with his hands yearned to build a dynamo. But as his father had been a railroad engineer, his interest was soon diverted to the electric car. He had organized one of the pioneer companies in the traction field in Chicago. He was a prolific inventor and would have done well if the curse of patent litigation had not wasted his time and used up his money. His principal assets now were the ownership of the underrunning trolley and a good deal of chastening experience.

A purchase was soon arranged; in March, 1888, Van Depoele arrived in Lynn, bringing his railway patents with him. The presence of this distinguished young European was somewhat awe-inspiring at first to Thomson's assistants. But they soon found that Van Depoele was a sensitive and gentle soul who asked only to be let alone while he worked at his inventions. He was given the post of consulting electrician and took it so seriously that he hired rooms next door to the factory and spent all his daylight

hours experimenting with models in the back yard. Beyond his house was a school, and the children used to line the fence at recess and gibe at this quiet stranger whose antics seemed to them so foolish. Van Depoele died at the height of his genius when only forty-six, from muscular rheumatism contracted while making an electric installation in a western mine.

Van Depoele, Thomson, Rice, and Rohrer formed the spearhead of the attack upon the trolley-car problem, with the Belgian in the lead because he had had the most experience. At once the factory began to build a car to be tried out in Lynn.

Van Depoele strongly advised installing the electric motor on the front platform beside the motorman, as he himself had done for years, transmitting the power to the wheels through a chain. This was clumsy and noisy, but he believed it was the only way to make the machine accessible for the endless tinkering that must be done on brushes and commutator. Rohrer agreed; he knew just how unmanageable those brushes were. He had spent a good part of the last three years explaining to customers that sparking was an evil that must be put up with if you wanted to ride with electric power.

But Thomson said no. The place for the motors was on the axles, where they could be connected to the wheels by simple gearing; where they would be out of the way and efficient. That mechanical concept, he insisted, was fundamental and must be satisfied first. Bad as the brush problem was it could not be allowed to interfere with logical design. Once a standard scheme of power transmission had been adopted something could be done about brushes.

With this farsighted policy to guide them the Lynn company began building their own trolley cars. Thomson, with Rohrer's practical help, designed a motor with such excellent electrical proportions that the brushes did not have to be shifted for different loads or reverse. This was a fine start. Several railway contracts were obtained and quite a number of cars put in service. Success seemed assured if only the operators of the cars could be made to understand their limitations.

But that proved impossible. The traction companies seemed to delight in cramming the little cars with passengers and then expecting them to grind up steep hills. Their motormen refused

to turn the power on gently; service mechanics did not bother to keep the machines cleaned of mud and grease. Motors were forced to run without overhaul till their commutators were worn ragged.

Complaints poured into the factory; Rohrer and his crew of trouble shooters spent their entire time traveling back and forth replacing worn parts and trying to appease irate trolley-car presidents. The factory was clogged with machines returned for repair. The Jonah of the situation was the hard copper brush.

"Professor Thomson and myself," said Rice, "became thoroughly discouraged and alarmed. A number of different forms of high-resistance metallic brushes were devised which helped matters but little and the situation rapidly became desperate."

They all realized that a radical departure must be made in brush design or else the traction job must be given back to the horse.

"The matter was frequently discussed with Van Depoele," Rice went on, "and he naturally urged that we should put the motor up in the car again, where it could be seen and its commutator properly watched. However, this solution was not satisfactory, and even Van Depoele admitted the method we had adopted was greatly preferable."

It was characteristic of Thomson that in a crisis of this kind he insisted on going forward, not backward. He was following exactly the same pattern as Edison, of whom Francis Upton once said, "I have often felt that Mr. Edison got himself purposely into trouble by premature publications and otherwise, so that he would have a full incentive to get himself out again." Like Edison, the Professor knew instinctively that when the problem became desperate enough it would be solved.

One day Van Depoele said rather hopelessly to Rice, "Why don't you try a brush made of carbon instead of copper?" Rice turned on him in astonishment. The idea was obviously absurd.

"Why, Mr. Van Depoele," he pointed out, "carbon has a resistance a thousand times that of copper, and it would be impossible to carry the current through it to the commutator." Wilbur Rice had been concerned with motor development from the beginning; he knew as well as any other man living that the brushes must convey current to the rotating part of a motor without blocking it with unnecessary resistance.

"Nevertheless," Van Depoele persisted, in his courteous European way, "I once tried carbon brushes in Chicago and they worked. I even applied for a patent on them."

Rice was enough like Thomson to recognize a ray of hope when he saw it. He asked the Belgian what he had tried them on. Van Depoele told him, a little diffidently. He had been working with an arc-light dynamo one night. One of the metal brushes had slipped out of place and had dropped through a crack in the floor. The lights had gone out. In the darkness Van Depoele could not find the brush, so he pushed a piece of arc-light carbon into the machine and started it up again. This substitute brush had worked perfectly. Later, he had tried the idea on a small motor installation with such good results that it had seemed worth while to apply for a patent on it. But other work had come along and he had never taken the patent out. The carbon brush had lain forgotten for several years.

Rice felt pretty doubtful. A motor requiring only a few amperes might work with carbon brushes, but you could hardly expect to get fifty amperes into a railway motor that way.

Van Depoele said eagerly, "I will try and see. At any rate it cannot behave any worse than what we have at present."

Rice consulted Thomson. The Professor was doubtful, too. Common sense had ruled out carbon for brushes long ago. But he agreed that the idea was no more absurd than some other impossibilities that had worked.

In his "Men and Volts," John W. Hammond tells the story well:

> So the trial was made. Van Depoele and Rohrer fitted extemporized carbon brushes to one of the standard F-30 motors and gave it a test. Rohrer was delegated to inspect the motor every half hour. Before long he reported with considerable excitement that the commutator showed not the slightest sign of sparking and was taking on a smooth, glazed surface.
>
> A severer test was immediately conducted, with a fairly heavy load. Still no sparking, not even when the direction of rotation was reversed.
>
> The good news was all over the plant.

Professor Thomson was quickly summoned. He stood looking at the world's first sparkless commutator a moment and then said,

"Van Depoele, that is the solution we have been looking for. You have showed us something that has been right in front of our eyes for years." That same day he had a set of carbon brushes made up and sent Rohrer to Woonsocket to install them on a car. Whereupon the ailing little trolley ran for 4,000 miles without brush trouble.

Meanwhile the testing men got busy on exhaustive experiments in the factory. They found that the new brush performed like a miracle on every machine. They found, too, that it was no miracle, but the simplest kind of logic. Carbon, being glass smooth, did not wear the commutators but polished them. Its resistance, as Rice had said, was a thousand times too high. But it was only necessary to give the new brush a thousand times the area of contact in order to drop its resistance to that of the finest copper. Until Van Depoele suggested it, every engineer in the world had ignored that simple bit of reasoning.

In this quiet way what Thomson called "the most important invention ever made in the electric railway field" came to light in Lynn. Without it the trolley car would have remained the wobbling little horse-car without a horse indefinitely. For no other solution for the brush difficulty has ever been found.

The effect on the traction industry was immense. In a year or two trolleys were appearing on the city streets all over America and Europe. Thomson-Houston, latest comer in the field, was now well in the lead. By his unerring faith in men of ideas, Professor Thomson had chosen the one man whose invention had brought a revolution in the business.

And the simple little carbon brush, having rescued the trolley car, went on to conquer new fields. With some doubt as to its value Thomson now applied it to the dynamo and was again rewarded. By altering the magnetic effect of the armature on the field of the machine it permitted an enormous increase in the effective use of materials throughout and was ultimately responsible for a large reduction in the cost of all direct-current machines.

Important as it was, the carbon brush got no headlines in the papers. So far as the public was concerned, the trolley car was a joke one day and modern transportation the next. City officials

kept on objecting to it on the same old excuses of danger and expense. The United States Senate, sitting in its capacity as governing body for the District of Columbia, framed a resolution forbidding the Thomson-Houston people to erect overhead trolley wires in Washington. If this ruling were to go through, its powerful precedent would drive the company off the nation's streets. For Sprague patents would prevent Thomson-Houston from laying its wires underground.

A company attorney hurried to the Capitol and attacked the resolution at a public hearing of the Senate. "No doubt," he cried, "there is danger in electric wires, but the danger to people generally in the city is extremely small. The danger in crossing the streets is thousands of times as great. The danger on the railroad train, on the steamer, in eating your lunch or drinking soda water, is far greater; you do these things without a care for the consequences. The other day I read of two fatalities caused by falling bricks from a chimney, but the paper said nothing about a proclamation by the mayor ordering all chimneys taken in."

The resolution was killed. Coffin had seen to it that he had lawyers as well as inventors whose minds were looking ahead.

Professor Thomson never knew how close his carbon-brush trolley car came to being defeated by Washington's politicians. He was busy in the model room making the magnetic blowout switch that would give the cars modern control.

I

Chapter 17

When Edison opened the Pearl Street Station in New York in 1882, he faced the serious problem of current measurement. The arc-light people had been giving their customers a flat weekly rate for the use of each light. Edison couldn't do this because his incandescents were so small and were used so intermittently. He needed an accurate meter that would register the total electric power used by each customer in a given period.

In those days the modern unit of power—the kilowatt-hour—had not been devised. Nor were there instruments of any sort except the cumbersome Wheatstone bridge and galvanometer. Edison therefore had to devise a system of his own or let his customers have their current free.

The problem was difficult because the meter had to be dependable and cheap and very accurate. If it were not the customers were sure to howl. His solution was typically Edisonian in its simplicity. He would use the time-honored principle of electroplating, in which a known weight of metal was transferred from positive to negative plate by each ampere of current in a given time.

The successful Edison meter is thus described by John W. Hammond:

> A fraction of the electric current which entered the customer's premises was diverted through a pair of cells, each containing two zinc plates immersed in a solution of zinc sulphate. The cells, connected in series, served as a check upon each other. Zinc in proportion to the volume of current was removed from the positive plate and deposited on the negative plate. From weighing the plates before and after use, the amount of current consumed could be calculated.

Electrolytic meters appeared in the United States by the thousands. Each Edison company had a regular meter crew that

went around collecting the plates once a month, taking them back to headquarters to be weighed, and so computing by a formula what quantity of electricity each customer had used. This operation had to be extremely accurate, since the monthly change in weight amounted to only a few thousandths of an ounce.

Tiny errors sometimes resulted in fantastic bills. A small clothing store in Pennsylvania was once charged $200 for a month's current. The proprietor protested violently. As Hammond has it:

"The meter man was aghast. He lost sleep for two nights. Then suddenly the explanation came to him. In order to fit the plates into the meter box he had been obliged to clip off an inch or two of copper connecting wire, forgetting that he had previously weighed the plates, wire and all. The loss in weight represented by two inches of wire had registered about $150 to the customer's debit."

For seven years the public accepted this clumsy system of admitting the electric light man to "weigh the bill" every month and did not realize how crude it was. Electricity had brought such magic anyway that the electrolytic meter was considered one of the marvels of the age, creating more humor than hardship. But when the electric motor began to invade the country the situation was quickly changed. Large quantities of power could not easily be measured by Edison's invention. The only alternative was the flat-rate method, which was fair neither to the customer nor to the power company.

During his work with trolley-car motors Professor Thomson came to the conclusion that a simple mechanical meter must be devised—a meter such as the gas companies used, that registered the total of the commodity consumed on dials that could be read direct. The electrical trade was clamoring for such an instrument. Accordingly, about 1889 he attacked the problem. The general solution was in his mind when he began. The essence of the invention lay in the expert handling of the details.

The principle, which seemed to him obvious but had escaped everyone else, was that of a tiny electric motor connected into the circuit to be measured. The power to drive it would be nearly zero, but not quite, and always proportional to the main power being consumed. The shaft of the motor would operate a train of

dials for registering the total energy that had gone through the circuit.

The beauty of the conception lay in Thomson's method of causing the motor to maintain the right proportion always. This he did by connecting its revolving part across the line, to respond to voltage, while the field coils were energized by a portion of the current going to the customer. Thus the device actually measured watts of electric energy, and its total revolutions registered on the dials as the number of kilowatt-hours consumed.

Though it sounds complicated to one who is unfamiliar with the interaction of electrical forces, the Thomson "recording wattmeter" was in fact so simple in principle as to be an insult to all who had failed to discover it before. Actually Ayrton and Perry in England had tried the motor principle without success, mainly because they could not attain the delicacy necessary to make the instrument accurate.

Nor did Thomson succeed easily himself. There were many bothersome problems, which kept him at work for nearly two years. A typical difficulty was the design of a damping device or "load" to prevent the motor from running away. This the Professor solved by recourse to Faraday's disk experiment. On the shaft of the tiny motor he mounted an aluminum plate revolving between the jaws of several permanent magnets. The eddy currents induced in this plate by the magnetism acted as a brake with a force just proportional to the speed of the shaft. It was the only way that an accurate meter could be made.

A second problem was the commutator, that bugbear of all motors. Thomson overcame this difficulty by using solid silver bars and brushes. Silver has the lowest electrical resistance of any metal. As for the rest, it was mostly a question of delicate proportion of parts and utmost skill in workmanship. The Professor worked long and lovingly over every detail, sketching design after design, which Robert Shand and his expert model makers put together for exhaustive tests.

While work on the new meter was at its height, George Westinghouse paid a visit to Lynn to try to buy Thomson's welding patents. The Professor had no intention of selling them but was glad to make the acquaintance of the man who had become such a vigorous rival in the alternating-current field. He took

Westinghouse through the plant and showed him everything except the meter and a few other things not yet patented. Afterward they sat down in the Professor's office to discuss the progress of the electrical art. Among other things they touched upon the serious need for a good wattmeter.

"It will have to be mechanical," George Westinghouse said, "and operate dials so that the customer can read it himself."

The Professor admitted that this was the only satisfactory solution.

"Some day," Westinghouse mused, "some damn fool will invent a real meter of that kind."

"Some day some damn fool will," the Professor agreed, pushing shut a desk drawer in which some meter parts lay exposed. He could have told him then who the damn fool would be, but he wanted the fun of thinking how discomfited George Westinghouse would be when he found out for himself.

The denouement was rather more dramatic than Thomson expected. After the close of the Paris Exposition in 1889 the municipality engineers, noting that no meters had been shown, offered a prize of 10,000 francs, to be paid the following year to the inventor of a meter which would measure both alternating- and direct-current power. Word of the prize came to the Professor in Lynn. At the time his wattmeter was just in that stage of final development and early production which kept Rohrer running up and down between Thomson's office and the factory, making small changes, testing, changing, and testing again. The Professor told Coffin that he thought they could "lift that prize" if they could get the meter done in time.

Rohrer went to work with greater zeal than ever. One Sunday morning in 1890 he realized that the deadline for entry was very close—the meter must be sent to Paris immediately, and by messenger. Rice chose a young expert by the name of Edgar Mix to carry the precious burden and hustled him off to France on three days' notice. Mix was rather annoyed when he was told that he would have to stay in Paris for a month or two to explain the meter and make tests for the committee.

Mix was in France eighteen months and came home only to return there for good. What had happened was that the Thomson meter was snapped up by the French engineers even before the

municipality had had the chance to award it the prize. Mix stayed to found the French Thomson-Houston Company, to exploit the meter, and later to introduce Thomson inventions to all Europe.

It happened that Professor Aron of Paris had also submitted a meter to the contest, which met the prize conditions. So Thomson and he divided the 10,000 francs. But the Aron meter was not a practical success. It used the principle of the swinging pendulum, like a clock, and while it was accurate at first, it could not stand long service. Thomson's instrument, on the other hand, would last indefinitely. It became the standard in Europe and America. Three years later, at the Columbian Exposition in Chicago, it was not entered in the meter competition at all. Professor Ayrton, managing the instrument awards, had asked Thomson to let him use it as the criterion by which all others should be judged.

Professor Thomson considered the wattmeter to be one of his most important contributions to inventive engineering. For many years he continued to apply various original ideas to the problems of electric measurements, and in 1895 patented the "inclined coil" instrument, his second major invention in this field. Voltmeters and ammeters of this type were made by the thousands and for a long time were virtually without competition in alternating-current work.

The establishing of the Compagnie Française Thomson-Houston set the stage for the spread of the Professor's work throughout the world. In a short time the Union Elektricitäts Gesellschaft was added in Germany and the British Thomson-Houston in England. In just ten years the youthful high-school teacher had progressed from the bottom to the top of the business world.

His return from Europe in the fall of 1889 might have been a public triumph if he had wished it so. But he did not. He desired only to continue in the work so well begun and to begin to live the private life he had neglected so long. To this end he bought an estate in the near-by Lynn suburb of Swampscott and began to build a house of ample proportions, overlooking the sea. There were two sons now, and Mrs. Thomson needed more room.

By today's standards the Swampscott house, with its elaborate woodwork and many large rooms, would be considered a mansion.

Elihu Thomson thought of it only as a place of comfort and seclusion, which he had fairly earned. Here, he hoped, he could carry on experiments of his own choosing after the day's work was done.

But his hopes were to be delayed. There were still many business obligations to be fulfilled.

2

As the nineties began, the Chinese puzzle of electrical development was getting more and more complicated. The welter of small companies had grown legion, every one with its pet patents, every one trying to build the same apparatus and make a commercial success of it. This was not possible. There was only one right path for the development of electrical engineering—a path too narrow for bitter rivals constantly at each other's throats. None of the great branches of the art could be properly advanced so long as every important invention was sure to be an infringement.

The situation was virtually a deadlock. Constant court action kept men like Thomson, Van Depoele, Sprague, Brush, Stanley, and hundreds of others harassed, forced them to waste their time preparing arguments and briefs, drove them to expend their splendid talents not in outwitting nature but in sidestepping each other.

Late in 1889 the confusion was made complete by the famous Edison suit against all infringers of its incandescent lamp patent. Every company in the United States and several abroad were forced to come forward and defend themselves. Preliminary skirmishes had begun in 1886, but the forces were so large and the technical situation so involved that it took three years for the main action to get under way. The engagement lasted for twenty-one months, bringing in the most skillful generals of the legal profession, receiving expert testimony from every great pioneer and many of the leading artisans of the day. It ended in a total victory for Edison. His lamp was judged the original and only practicable method of electric lighting by incandescence in a vacuum.

The decision gave the Edison enterprises a tremendous opportunity to snatch the lion's share of the electrical business. Already

they were the largest unit in the field, with no close competitor except Thomson-Houston. From a small factory at Newark, N. J., Edison had expanded to Menlo Park, then to Goerck Street in New York. The building of dynamos and lighting gear had put such a strain on this plant that the inventor had had to get permission of Tammany Hall to put machine lathes on the sidewalks and run them by belts through the factory windows. Soon afterward he had bought an unoccupied locomotive works in Schenectady, N. Y., and had consolidated all his manufacturing under the title of the Edison General Electric Company.

With the new patent victory in hand the Edison executives at once began a vigorous campaign of injunctions against all infringers. It was time, they decided, to clear the air.

But there was one flaw in the plan to make the Edison interests supreme. They did not possess all the electrical talent in America. In fact, most of it was scattered around among the smaller concerns. The lamp suits had generated much bitterness, and these able men were determined not to be driven from the field. They still held so many vital patents that they could prevent Edison from getting control. Thomson-Houston, in fact, was making the best incandescent lamps on the market, using Thomson's own subsidiary patents. These lamps actually sold for a considerably higher price and could still compete. Though the Lynn company could be enjoined from further manufacture, Edison could not benefit by the improvements and his customers were sure to complain.

Charles A. Coffin had understood this situation perfectly and had long ago made up his mind to capitalize on it. He had already put a brilliant lawyer named Frederick P. Fish in charge of his legal forces and had begun buying the smaller companies, gradually working toward an organization even stronger than Edison's. Brush had come to Lynn in 1889, Sprague soon after. Others had followed. Soon the pooling of talent against Edison would be complete. Today such action would instantly bring on a government antitrust suit. Fortunately there was then no Sherman Act; a business genius was free to perform the consolidation which saved the electrical art from chaos and destruction.

Coffin's talent for this consolidation was beautifully illustrated in 1893 when, at Rice's suggestion he bought the company which

employed Steinmetz. The little German hunchback had fled his country in 1889 as a socialist outcast and had arrived in America with only the proverbial dime in his pocket. He had found work as a draftsman with Rudolph Eickemeyer, in Yonkers, N. Y. The firm made railway motors in a small way, and Steinmetz showed such talent for the theory of electrical design that he soon became Eickemeyer's main reliance in the scramble of competition. At twenty-six he discovered and published the "law of hysteresis," which explained the hitherto obscure magnetic losses in alternating-current machines. The paper caused a ripple of interest in mathematical circles and was then forgotten.

But at that moment one of Thomson's engineers was struggling with the design problems of a large dynamo for the West End Street Railway in Boston, which had offered the company a contract worth over a million dollars. This man happened on Steinmetz's article in a moment of desperation and got so much help from it that he showed it to the Professor. Thomson was so much impressed that he sent Rice to Yonkers to interview the unknown young man and invite him to join the company in Lynn. Rice later described his dramatic meeting with Steinmetz thus:

> I was startled, and somewhat disappointed, by the strange sight of a small, frail body, surmounted by a large head, with long hair hanging to the shoulders, and clothed in an old cardigan jacket, cigar in mouth, sitting cross-legged on a laboratory work-table.
>
> My disappointment was but momentary and completely disappeared the moment he began to speak. I instantly felt the strange power of his piercing but kindly eyes; and as he continued, his enthusiasm, his earnestness, his clear conceptions and marvellous grasp of engineering problems convinced me that we had indeed made a great find. It needed no prophetic insight to realize that here was a great man, who spoke with the authority of accurate and profound knowledge, and one who, if given the opportunity, was destined to render great service to our industry.

Rice's enthusiastic report on his return to Lynn resulted in a conference with Thomson, Coffin, and Frederick P. Fish. Steinmetz was willing to come, Rice told them, delighted to come, in

fact, but Eickemeyer had other ideas. The loss of "Carl," he had said, would wreck his business. It looked as if Steinmetz was not to be lured away.

Coffin made up his mind at once. "Professor," he said, "you and Fred go down there right away. If this young man is as good as Rice says he is, buy the company outright."

Thomson and Fish went. The lawyer examined Eickemeyer's patents while the Professor talked to "Carl." When they came away their minds were made up. The patents were not worth much but Steinmetz was. They would buy the concern.

Within a few months Steinmetz was established at Lynn, beginning the career that was to make him famous throughout the world.

Coffin's practice of buying the future, however steep the price might seem at the time, had proved its value again.

Back in 1891 Coffin's policy had already accomplished its result so well that the Edison forces were becoming alarmed. The million-dollar Boston contract was the last straw. It called for a dynamo of two thousand kilowatts, the largest in the world. If the project succeeded Thomson-Houston would be top dog in the electric power field.

President Villard of Edison General Electric came to Lynn with an assistant, to see if it were possible to buy this competitor out. Rohrer was delegated to show them the plant, which he did with zeal, determined to impress them with the formidable character of their opposition. His prize exhibit was Professor Thomson, who in a most friendly way explained his future expectations in the engineering field. It was a familiar situation to him, and one which he loved. He had done the same thing with Churchill long ago. But the Edison people were gently told that the Lynn company was not for sale.

Nearly a year went by as the situation steadily tightened. Coffin resisted all suggestions for making the first move, sticking to his business of "sawing wood."

Late in 1891 the Edison firm required large sums of new capital to meet the demands of expansion. J. P. Morgan, who had financed Edison for years, sent his associate, Major Twombley, to survey the company's plants. For the sake of comparison the

Major, on his own initiative, included Lynn in his trip. When he returned he had a discouraging report for Morgan. "I wouldn't advise touching this Edison deal unless the Thomson-Houston company is included," he said.

"What's Thomson-Houston?" the financier demanded.

"A Boston firm," the Major told him.

"Boston!" cried Morgan, in a tone that implied, "Where's that?" He looked at Twombley impatiently. "Well, send them down here to talk to me."

Coffin was notified and presently appeared at the Morgan offices. The crusty old banker intended to make short work of this provincial young upstart but after he had listened to him for a few minutes, he changed his mind. Before the interview was over, Charles Coffin had persuaded him to finance not a purchase but a consolidation.

The affair moved swiftly to a close in 1892, and in June there arose out of the chaos of infringing patents a new electrical unit known as the General Electric Company. Its future was assured, for it possessed practically all the engineering and managerial brains in the electrical industry. The only real talent left outside was Westinghouse and his brilliant young assistant, Nikola Tesla, who spent the next ten years in very hard sledding indeed.

The provincial Mr. Coffin, whom Morgan had wanted to eliminate, became the president of the new concern, and through his wise guidance, General Electric and the large number of Edison light companies it controlled passed safely through the financial panic of 1893, which wiped out millions in American investments. Professor Thomson became the leading technical expert for the whole group and Coffin's main reliance in the great trek forward into the future.

At first Thomas Edison sat on the board of directors as a consultant. But his sympathies were not with the great combine, nor his talents on the administrative side. Soon he retired to make a brand new start of his own and gradually to rest on his laurels. His greatest work had been done. His magnificent contribution of the incandescent lamp could now go on better without him. But the magic of his name was forever to be perpetuated in the companies which were to bring electricity to the people.

Chapter 18

I

The effect of this vast business change upon a lesser man than Thomson would have been profound. Many of his associates, indeed, disappeared within the organizational maze to be lost to a fame they might have had in less overwhelming surroundings. But in the Professor there was no change. He merely went on as before—kindly, inspiring, busy, the same master of his destiny that he had always been. He was neither awed by the young giant he had helped create nor spoiled by it.

When Coffin and Rice begged him to become a director of the company he declined, saying simply that his value to the company was in the realm of new ideas rather than in management. He preferred the quiet of his own thoughts and the new concepts they would bring. When he was invited in 1897 to become the president of the Massachusetts Institute of Technology, he refused for the same reason. "I am not an executive by nature," he wrote. "Nor have I any wish to become a public character. To secure the good opinion of those whose opinions I value satisfies me."

The men to whom he referred were the scientists, here and abroad, whose acclaim had been so generously given.

The improvement of electrical machinery along the natural channels of alternating current was now in the hands of Steinmetz and the many able men Coffin and Rice had attracted to the company. Thomson felt it was time for him to withdraw from the onerous duties of development work and direct his efforts more toward research in untried fields. Actually he never accomplished this separation fully, for there was no man in the organization who could equal him in penetrating to the root of a practical problem. But the moment of the consolidation was his point of departure. He was now comfortably well off and could afford to do only the work he chose.

The problems which began to interest him now were scientific rather than engineering in kind, harking back to the Philadelphia days when he and William Greene had speculated through all the wide reaches of physics and chemistry. He approached them now joyfully, as one who had earned the right to freedom. As always, he was surrounded by assistants who were his devoted pupils. In this new venture the chief of these was a young man called Hermann Lemp.

Lemp had come to America from Switzerland and found work with Edison in 1882, designing a machine to make lamp filaments. Under the great man's keen eye he had developed his own considerable talent for invention, learning to think directly in terms of practical machines. Edison had taught him the secret of it in his own abrupt way. Appearing suddenly behind him one day he had barked, "You have lost a whole week making those drawings. Why don't you make the *machine!*" Lemp had not missed the lesson, and presently produced a lamp improvement of his own which was important. After moving through a succession of small Edison companies he had come to Lynn in 1887.

Lemp was an exultant young man who fell instantly into step with the Thomson method. His first working mate was Rohrer, and his first adventure a night spent with him on Revere Beach trying out a new searchlight Thomson had designed for the Navy. He and Rohrer spent their time pestering the lovers along the shore. "Many a tête-à-tête was broken up," he says, "when the blinding beam of the light struck the bushes." They judged that the Navy specifications had been satisfied.

Lemp was amazed when he found out which man Thomson was. He had expected an imposing person—"a kind of domineering intellect," to whom one would never speak unless spoken to first. With hard years of rigid European teaching behind him, the Swiss youth could not believe that this gentle man who would go to any trouble to explain a point to a subordinate could really be the presiding genius of the company.

Thomson took an instant liking to this young fellow who obviously possessed the inventor's resiliency of mind and mechanical courage. As soon as he had sized him up he put him in charge of the welding company just then starting up. Lemp stayed there five years, during which he was in constant consultation with the

Professor, making improvements in the machines and thinking up new applications. As Rice had been before him, so was Lemp a perfect anvil upon which Elihu Thomson could strike out a constant shower of sparks. They spent hours together, discussing, planning, dreaming about the future—talking about everything under the sun.

One of Lemp's particular cronies in these first days was H. Percy Maxim, to whom Thomson had given a start as a designer. Maxim soon drifted away into the electric carriage business and later became famous for his gun silencer and other ordnance inventions.

Percy Maxim was only one more of the widening circle of men who obtained their early inspiration from Elihu Thomson. The secret of this inspiration was the Professor's informality, his talent for infusing into every contact with others a personal quality, a readiness to give of his time and thought to any problem, large or small. As his friend Dr. Wolbach said of him years later, "He never assumed that you couldn't comprehend."

The consequence was that everyone who knew Thomson, even slightly, loved to listen to his discourses and took every opportunity to start him talking, whatever the subject might be. His fascinating explanations captured the interest of anyone within hearing, whether professional or not. Without changing the style of his presentation in the slightest he could command the attention of a child or a plumber or a college president.

Hermann Lemp was crossing Lynn Common with him one day when the Professor saw a laborer hacking at a trolley rail joint with his pick. He stopped and gave the man a long and careful explanation of why the rails had to be solidly welded together to carry the current from the cars back to the power station. The laborer listened to every word and thanked him profusely. For the first time in his life he understood the purpose of the job that earned him his living.

Sometimes at a dinner the Professor got so immersed in an explanation he was making that he forgot what he was doing. At a monthly luncheon of the engineering staff one day he was holding forth when the collection plate came around for the usual fifty-cent contribution. Still talking full blast the Professor threw in his fifty cents and took out a dollar in change. Lemp touched

his arm and whispered, "Professor, what are you doing?" Thomson looked down and then grinned sheepishly at his audience. They burst out laughing and clapping. "He looked so funny," said Lemp, "we all wanted him to keep the dollar. But he wouldn't."

It was in the swift-moving years of the nineties that Thomson developed the art of inspiring others to make inventions as important as his own.

For a time the welding company prospered, spreading the invention far and wide over America and Europe. Applications for the new art were innumerable. Electric welding could join wire, make brass and copper pipe, fashion hardware for the carriage trade, build wheels for wagons and railroads, splice steel cable, forge links for chain—in fact do almost any job where metals had to be joined. Lemp's job was to design the special machines for each new application and get them built. At one time he even turned out a tiny welder for making gold wedding rings, which was used by a jeweler in Providence, R.I., for many years.

But when the panic of 1893 struck, the welding company fell on hard times. For some reason Thomson had not been fortunate in his choice of men for the management of the concern. They had allowed the business to expand too fast. Though Thomson went to its rescue as well as he could, it was a long time before the welding company was on a sound footing again.

During the depression the company let Lemp go. This was such an obvious mistake that Thomson made a protest to the management. When this did no good, he took Lemp on as his special assistant in the model room at the main factory. In the next five years the team of Thomson and Lemp roamed the whole field of science and engineering for new worlds to conquer and produced some of the most important inventions of the times.

For the moment welding work was left in abeyance, though special uses for it were constantly suggesting themselves.

The story of one such use Thomson loved to relate as an example of the endless welding applications. One morning Lemp came into the office to find his chief in a fine state of upset. He needed some important patent records for a meeting but they were

locked in the safe and couldn't be got out. His secretary, John W. Gibboney, had recently died and the combination was lost. They hunted high and low for it and finally decided that Gibboney had taken it with him in his head. Thomson telephoned the makers of the safe in Boston but could not get an expert for twenty-four hours.

Lemp said, "Professor, if you will stand the expense of repairing it I'll open that safe." Thomson agreed at once. Lemp strung a pair of wires to another building and by means of arc-welding electrodes burned a hole through the safe lock and got it open in about ten minutes. The Professor snatched out his records and gave him a boyish smile. "Now, Lemp," he said, "we will have to keep this thing dark. Otherwise all the burglars will begin to buy arc-welding apparatus."

2

On the brink of the depression, which almost ruined the new General Electric Company and did ruin hundreds of other concerns, the City of Chicago put on the first great world's fair in America—the Columbian Exposition of 1893. To the general public, hardly remembering the Centennial at Philadelphia seventeen years before, the amazing progress demonstrated by the Fair was not particularly noticeable. They scarcely realized that they had been living through a profound technical revolution which had brought a brand-new standard of living. But Thomson and Lemp realized it. As they visited the huge fair grounds in Jackson Park together they were positively exultant at the change wrought in less than twenty years

Electricity had suddenly become king. Electrical apparatus, which had occupied a few insignificant booths in 1876, now had a vast building of its own, and its influence was unmistakable everywhere. The contrast which the Professor's vivid memory of the Centennial conjured up brought deep satisfaction to his heart, for he himself had had a large share in making this change. Those clattering little devices, all run by the giant Corliss engine, were here replaced by thousands of smooth-running machines, almost all of them driven by the electric motors he had helped pioneer. Here electric current was busy working elevators, driving mining and industrial machinery, charging storage batteries, doing a hundred kinds of welding, forging, machining, heating.

He had had a hand in every application. Atop Machinery Hall in Philadelphia had been a single arc lamp, largely ignored. Here, in this one building in Chicago two thousand arcs furnished a brilliance that was greater than daylight. He had been among the earliest in the arc-light field.

The Electrical Building was a paradise of special demonstrations and experimental apparatus to which every company had contributed its newest and most striking ideas. Here was shown Thomson's latest invention—a high-frequency coil giving a steady roaring spark 65 inches long. This was the first public showing of the device later applied to medical treatment under the mistaken name of the Tesla coil.

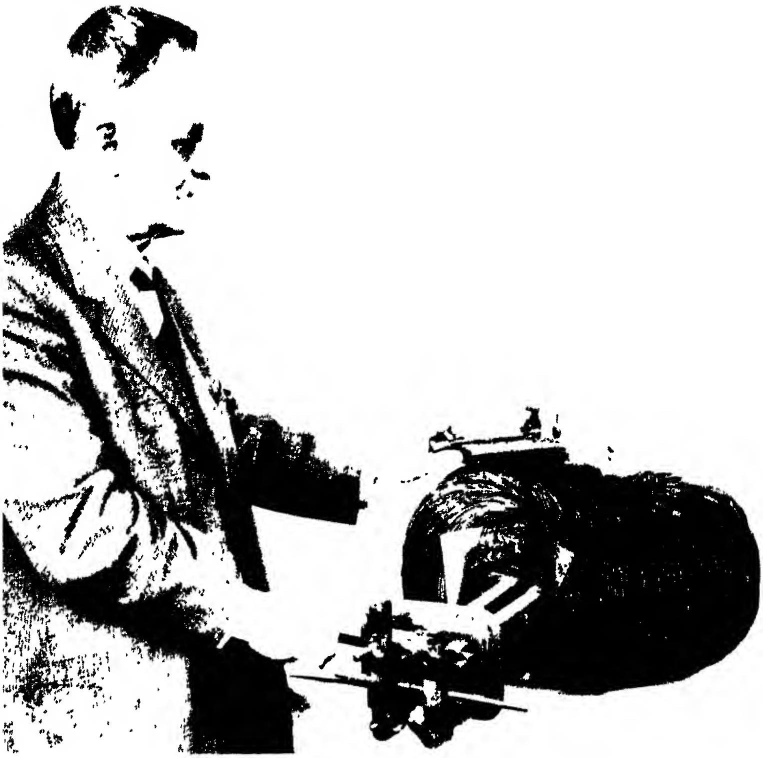
Outside in the Exposition grounds electricity was likewise the master of ceremonies. Nearly one hundred thousand incandescent lamps* lit every corner of it. Visitors were carried up and down the main thoroughfare on a moving sidewalk which could accommodate six thousand seated passengers at one time. An electric railway served all parts of the grounds. And on the lagoon a fleet of fifty gondolas, propelled by electric motors, took them for thrilling rides.

To furnish the motive force for all this there was a gigantic power plant—the largest aggregation of steam engines and dynamos in the world—most of them showing the influence of the Professor's own design. One direct-current generator alone produced 2,000 horsepower—twice the amount delivered by the famous Corliss engine of 1876. But best of all, the electric lighting throughout the Exposition was operated by the system of alternating-current transformers which he had originated.

Of all the millions who saw the Exposition there was probably no happier man present than Elihu Thomson.

There was not much time, however, for the Professor to indulge in exploration. Serious business was at hand in the International Electrical Congress which the Exposition was sponsoring. This, too, was bigger and better and more brilliant than any other in the history of the science. It was the first gathering of its kind to be officially sponsored by the *governments* of the great

* These were hybrid "stopper lamps" devised by Westinghouse to circumvent Edison's designs and hold the market till his patents on sealed bulbs ran out. They were made like bottles with ground glass stoppers held in with cement.



Thomson and his original "jew's-harp" welding transformer.

countries. It included delegates from the United States, Canada, Great Britain, France, Germany, Italy, Austria, Switzerland, Sweden, and Mexico.

The galaxy of notables was headed by Professor Helmholtz, the greatest living German physicist, who was made honorary president of the congress. Among the other great names were the celebrated French engineers, Mascart and Hospitalier; Ferraris of Italy; Thury of Switzerland; Ayrton, Preece, and Silvanus Thompson of Great Britain; and the Americans Rowland, Nichols, Mendenhall, Elihu Thomson, and Elisha Gray. Altogether the roster included nearly every important name in contemporary science except Kelvin, who had remained in England to testify in the notorious Harness Electric Belt swindle case.

The congress met and was opened by Elisha Gray, and, when he had made the address of welcome, Sir William Preece rose and asked the delegates to name Elihu Thomson as temporary chairman. The Professor was immediately chosen by acclamation and served in this capacity throughout the historic meetings.

The congress had assembled to reach final agreement upon the international units of electrical measure and to establish their permanent definitions. Having deliberated for the whole month of August, it passed a resolution establishing the ohm, ampere, volt, coulomb, joule, watt, and henry—covering virtually the entire field of electricity. When the delegates were not otherwise employed they listened to technical papers of all kinds.

One of these papers made engineering history. It was presented by Charles P. Steinmetz and offered a mathematical theory of alternating currents. A legend has grown up around this occasion. According to it, each speaker was allowed an hour to make his remarks, and could obtain ten minutes' extra time if he needed it. The vigorous young mathematician plunged into a discussion so abstruse that his audience had great trouble in following him. But in his eagerness to tell his story he forgot the people altogether and hurried along through his hour and twenty extra minutes of grace. Then the chairman firmly sat him down.

Steinmetz looked at him with a puzzled expression and said, "But I have just finished the *Introduction* to my paper!"

He was deeply hurt to find that the contribution he thought so important had only seemed to bore his audience. But he did not

lose heart. He was ahead of his time, he decided, and must patiently educate the scientific world to his advanced ideas. So he left the congress and retired to his study in Schenectady to put his theories down on paper in complete form.

Several years later Steinmetz published his alternating-current mathematics to the world—in a work of three large volumes. By this time he had an important place in the profession, and the great value of his contribution was recognized everywhere. But it was still so abstruse that few could say they found it easy reading.

Yet because of his picturesque deformity and strange habits of living he was idolized by thousands who could not possibly evaluate his contributions at all.

For a time Elihu Thomson had his two small sons Stuart and Roland at the Exposition and trotted them around, demonstrating and explaining everything to their intense delight. Although only seven and five years old, they were mechanically inclined and so spent their days in a ferment of excitement. Stuart, who was like his father in his talent for observation, noticed particularly how everyone seemed to know the Professor and to be his friend. Everywhere they went in the Exposition people stopped what they were doing to greet them and show them around. It was evident to the boys that their father was a very great man.

There was one occasion, however, that puzzled them a good deal, for the usual recognition was lacking. It was in the balcony of the Electrical Building, where were exhibited a wonderful assortment of quack devices for curing the sick—electric belts, hairbrushes, insoles, combs—cure-alls of every kind. Their father seemed suddenly possessed of the spirit of Old Nick himself, and as they watched with glee, he marched up to a young girl who was selling a body invigorator and began to pester her with scientific questions.

For a while the salesgirl kept her temper and talked back smartly, explaining with exaggerated patience how the electricity entered the body and what it did there. But their father waved all this aside and demanded to know the precise theory by which the apparatus worked. He said he feared it was all nonsense but just wanted to be sure.

By this time the young lady was thoroughly mad and shouted, "What do you know about electricity, anyhow?" so that quite a crowd collected. Then their father took them by the hand and led them away, chuckling. As they went the boys heard a man in the booth say to the girl, "Goodness' sakes! Don't you know who that was? That was Professor Thomson. He *invented* electricity!"

The story itself, told delightedly through the Thomson family for years, may itself be apocryphal. But the Professor's attitude toward quacks at the Exposition was certainly not. Before he went home he gathered all his scientific colleagues in a protest meeting at which they severely pilloried the Exposition managers for letting such fakirs appear side by side with bona fide engineering. Out of curiosity many of the quacks themselves came to the meeting and took a very apologetic tone when put on the carpet. Then they went back to work and continued happily swindling the public.

All his life the Professor crusaded against charlatans wherever he found them, often going to great trouble to expose these frauds. But, though he sometimes won, he never succeeded in killing the public's love of being taken in.

The grand finale of the Electrical Congress was a magnificent dinner at which every notable was present. All the great men were placed in a row at the speaker's table, a veritable frieze of historic characters ranged along the wall of the room. Hermann Lemp was seated just below with other Lynn men. In his memoirs he tells this poignant story of the evening's most dramatic moment:

> While the banquet was in progress, I noticed my old chief, Thomas Edison, coming in with Samuel Insull and seating himself at an out-of-the-way table. He was not a delegate to the Congress and so did not occupy a place among the speakers. The truth was that the theoretical physicists, particularly those from Europe, looked down upon Mr. Edison as not belonging to them, and in many instances acted snobbishly toward him. Though there was no slight intended on this night, they knew of Mr. Edison's dislike of public appearances, and had left him to himself.
>
> So it did my heart good to see Professor Helmholtz, one of the greatest luminaries among physicists, step down from the speaker's table and come over and shake hands with Edison.

Well, the usual speechmaking had begun and during a lull in the conversation the whole room began to rap the tables and call in a loud voice: "Edison! Edison! Speech!" Now Mr. Edison would never speak in public. So he got up, smiled and bowed around the room and sat down. Again the cries came: "Edison! Edison! Speech!" Again he got up, smiled and sat down. And then Professor Thomson, at the speaker's table, rose and said: "Well, if Tom will not speak, Tom's son will have to."

After the applause, my Professor gave a fine address, simple and to the point as he always did—quite the best speech of the evening.

3

Thomson and Lemp returned from Chicago to a different world. The panic had struck; General Electric, like every other large corporation, was running for cover, settling its obligations, making retrenchments, securing every open door and loose window of its financial structure against the coming storm. Charles Coffin believed his company, by making sacrifices, could ride out the blow. Ruthlessly he began to make preparations.

Salaries were cut, unessential men discharged, manufacturing schedules reduced to a fraction. The main dynamo and motor business was removed to Schenectady to take advantage of the larger shops, carrying with it the half-finished machines for the West End Street Railway. Rohrer, in charge of the job, had already gone. Coffin himself set up in New York, within a block of the battle line in Wall Street.

Wilbur Rice, now technical director for the whole concern, was sent to Schenectady on a double mission of great delicacy. Not only must he keep up production during the crisis, but he must establish peace and cooperation between the Edison and Thomson men who had so lately been bitter rivals. With Rohrer's help he must teach these professionally jealous people to live together under one manufacturing roof. That he succeeded at this, in the midst of the storm, showed the true genius he had for managing men.

In the meanwhile, humming little Factories A and B, once the cradle of the electrical arts, had fallen silent indeed. The famous model room had shrunk to a skeleton. Thomson and Lemp and

Robert Shand hung on almost alone. Even the flourishing incandescent lamp department had been transferred to John Howell at the Edison Lamp Works in Harrison, N.J.

It was in times like these that the starting up of new processes, the development of new inventions, took tremendous courage, judgment, faith—such faith as Edison had had in the earliest days of the incandescent itself. So typical was this faith, both in Edison and Thomson, that the story of the lamp has a special meaning here.

In 1882, when Edison had got his lamp into production and the country dotted with power stations to light it, he faced the serious problem of setting a fair price on the little 16-candlepower bulbs. They were so expensive to make that he had to decide whether to sell them at cost and strangle the business or to take a loss and bank on his ability to bring the cost down. In his own words this is what he did:

> The first year the lamps cost us about $1.10 each and we sold them for forty cents. But there were only about 20,000 or 30,000 of them. The next year they cost us about seventy cents and we sold them for forty. There were a good many and we lost more money the second year than the first. The third year I succeeded in getting up machinery and in changing processes until it got down so that they cost somewhere around fifty cents. I still sold them for forty and lost more money that year than any other because the sales were increasing rapidly. The fourth year I got it down to thirty-seven cents and made up all the money in one year that I had lost in all three previous ones. I finally got it down to twenty-two cents and sold them for forty cents, and they were made by the million.
>
> Whereupon the Wall Street people thought it was a very lucrative business, so they concluded they would like to have it and bought us out.

It was the same kind of faith in his own ability that Thomson must capitalize on now.

In spite of business worries, which he could not altogether shift to other shoulders, the Professor was happier than he had been for a long time. He and his men would be free to roam far and wide in search of principles that were new. These were

desperate times. Chances must be taken that in better days would have been a foolish extravagance.

At this time Hermann Lemp was still chief engineer of the welding company. But his job had dwindled to almost nothing; orders had stopped coming in. If the factory were not to close down altogether it was necessary to find something for the men to do. He went to the Professor in desperation and found that as usual his mind was bubbling with ideas. They sat down and talked things over. Out of the welter came three suggestions which seemed worth a try.

One was an internal-combustion engine run by kerosene, another a motor-driven refrigeration machine, the third, an electric furnace.

The kerosene engine seemed the least risky experiment, for a Swiss machine had arrived in this country which had possibilities if it could be improved. So Lemp made arrangements with the inventor, who was in New York, and rushed out improved designs. At first results were encouraging; the engine performed well and several were built and sold. But the kerosene exhaust made a terrible smell and could not be tolerated except in the open country where the wind blew it away. Soon the business had dwindled and died.

The refrigerator fared little better. Thomson's idea had been to devise a household model which would, as he said, "torpedo the ice man." With the help of the conservative householder, the ice man for the time being refused to be sunk. Electric power was not yet a home convenience; a private electric plant was too complicated and too expensive. The idea was there, but the practical embodiment of it had come too soon.

Thomson did not seem cast down. "It's too bad," he mused, as he and Lemp discussed the refrigerator's demise. "There is a saying in the good book that the bread which you cast upon the waters returns. But," he added whimsically, "it's very often somebody else's bread. And the man who invents a thing ahead of time is usually forgotten by the latecomers, who get the credit."

Both of them were to see a good deal more of this in the next few years. But their luck with the electric furnace was better. The smelting of metals by electric current, which they originated, has become one of the great factors in modern industrial technique.

Chapter 19

I

The years of depression passed. Professor Thomson went on as if they had never been. His duties were more varied now than ever—not alone to invent and improve, but to act as a sort of scientific court of arbitration to his whole profession. More and more, engineering authorities came to him for a final word in every controversy. Magazine editors sought his opinion in articles; societies listened to his speeches on subjects of ever-widening scope; scientists and inventors waited to see, with each new advance, what Elihu Thomson would have to say about it.

The word of the Professor was becoming something to conjure with.

There was a story in circulation which gave this attitude point. During the eighties the streets of every large city in America were disfigured by a forest of lofty wooden poles whose innumerable crossarms sagged with wires—telegraph, telephone, light, and fire alarm. It was a curse that seemed to have no cure, for the public utility companies found it more economical and refused to change to the underground conduits that Edison had found to work perfectly.

In the great blizzard of 1888 the havoc was enormous. All over New York City wires were down; the overhead system was almost a total loss. When the storm was over the mayor demanded that the utilities put their wires underground. They said this was impossible. When he threatened them with a city ordinance forbidding them the use of the air, the leaders of the industry went to Fred Fish in Boston and begged him to get Professor Thomson to come to New York and "bang some sense into the mayor's head."

"If I were you," warned Fish, "I'd drop that idea altogether. The Professor is a strong advocate of underground wires and has been for years."

The utilities took his advice. Without further struggle they began the change to underground ducts.

Professor Thomson was not even consulted. His name alone had been enough to win the fight.

When Lemp lost his job at the welding company he retired to a small room just outside Thomson's office and went to work for him exclusively. His first job was to adapt the principle of the rotary converter, which he and the Professor had recenty developed, to the operation of arc lights on alternating current. It was a full year's work which ended in partial failure and was finally abandoned. But Lemp had no time for regrets, for in the meanwhile one of the greatest scientific discoveries of all time had burst upon the world.

On November 8, 1895, Wilhelm Konrad Roentgen, professor of physics at the University of Würzburg, Germany, discovered a mysterious new radiation which he temporarily called the "X-ray." He had been experimenting with the well-known Crookes vacuum tubes, lighting them with the discharge from a Ruhmkorff induction coil. On this day he observed that a fluorescent screen which happened to be in the room was caused to glow by emanations from the tube which were not visible light. The glow still appeared when the tube was carefully screened with cardboard.

Roentgen was a man of the highest scientific integrity. He did not mention his discovery to anyone but began a painstaking investigation of it which occupied him for seven weeks. His first assumption was that he had found a new form of light, shorter in wave length than the ultraviolet, and capable of passing through solids. The long period of experiment seemed to verify this, for the X-rays could be reflected and refracted by wooden and metal lenses, prisms, and mirrors just as light could with glass.

But in the course of this scientific checkup Roentgen struck upon an application for the new rays more startling than the discovery itself. Various solid bodies were opaque to the radiation in different degrees, lead being the most and wood and human flesh the least. Thus it was possible to make shadowgraphs on photographic plates of metal coins in a leather purse, and of pens and pencils in a desk drawer. Most important of all, he got a silhouette of the bones in his own hand.

Professor Roentgen suddenly found himself at a scientific crossroads exceedingly rare in history. Here at the start two sharply divergent lines of procedure were offered: the purely theoretical research into the nature of the rays—which lured him mightily—and the immediate application of the discovery for public use. For it was at once obvious to him that the new photographic technique might revolutionize medicine.

His decision came at once: he would give up all thought of the money and glory that could come from patenting the discovery and give it immediately to the world for what it might be worth.

Without delay he communicated his findings to his local scientific society and then sent some of the photographs to a medical friend in Vienna with the request that they be broadcast to the scientific world.

Roentgen's shadowgraphs were first published on January 5, 1896. Soon after, he gave a public lecture in Würzburg, describing his experiments in detail and inviting all who cared to do so to help in the work of development. At one stroke he had made the X-rays public property and put them beyond the reach of private exploitation.

The news spread from Vienna with the speed of the telegraph. The next day London papers published it and sent it on to America. The historic message was this:

> The noise of war's alarms* should not distract attention from the marvelous triumph of science which is reported from Vienna. It is announced that Prof. Roentgen of Wurtzburg University has discovered a light which for the purpose of photography will penetrate wood, cloth and most other organic substances.

Full details of the discovery followed within a day, including the report that Roentgen was already photographing "broken limbs and bullets in human bodies."

The decision of this great and unselfish man to retain no part of the discovery for personal gain had a profound effect on the future of medicine. Instantly scientists, doctors, and photographers in all parts of the world—anyone who could make, buy, or borrow the apparatus—hastened to duplicate the German professor's

* The approaching Boer War in South Africa.

results. The amazing fact was that the Crookes tubes and spark coils necessary to produce X-rays were standard equipment in every laboratory and had been for years.

Not only this. Many prominent men, including Hittorf, Hertz, Lenard, and Crookes himself had for the past five years been investigating the "cathode rays" in vacuum tubes, which produced the X-rays whenever they struck a solid surface. Yet not one of these brilliant researchers had noticed them. Professor Goodspeed of the University of Pennsylvania had accidentally obtained an X-ray photograph in 1890 of some coins lying on a box of plates. He had failed completely to realize its significance.

In the headlong scramble to produce X-rays for themselves, physicists, chemists, doctors, and engineers dropped everything, threw the apparatus together, and went to work, Thomas Edison among them. Elihu Thomson waited only for official confirmation of the reports, then followed suit.

The earliest American success in point of time was secured by Professor Pupin at Columbia. Two weeks after the first German announcement, he took a radiograph of objects in a metal box with no other equipment than a modified electric light bulb and a small induction coil. A few days later a prominent lawyer named Prescott Hall Butler came to him with a serious shot-gun wound in his hand. Pupin tried to photograph it but the weak little tube required an hour's exposure, which the patient could not stand.

Pupin appealed to Edison, who had gone straight to work to discover better fluoroscopic chemicals; the inventor sent him a calcium tungstate screen which he had just found to be highly efficient. Putting the patient's hand in front of this, Pupin obtained a shadow image which he could photograph in a few seconds. With the resulting plate as a guide Butler's doctor was able to remove every one of the shot and save the hand. Pupin published an account of this, the first X-ray surgical operation in America, on February 12, 1896, but, in the storm of claims and counter-claims, he was never given credit for his photographic method. Butler, however, was so grateful that he offered to establish a fellowship for Pupin at the Century Club, entitling him to two rum toddies a day for the rest of his life.

The medical profession seized the new method with a fervor that was not to be seen again till the coming of sulfanilamide. In

that same month of February, 1896, photographs were taken of practically every part of the body, including the teeth and an unborn child, and some doctors announced the X-rays as a standard method of diagnosis. No one gave a thought to the possible danger of the new radiation; it was considered as harmless as visible light. Every investigator spent long hours testing the tubes with fluoroscopic screens, for the most part using his own left hand as the object to be photographed. Thus in those first eager months the unsuspected tragedy of the X-ray martyrs was begun.

Pupin himself would have been one of the first to succumb had he not had to abandon the research because of pneumonia and the loss of his wife.

2

In Lynn meanwhile Professor Thomson was viewing the matter calmly. As a scientist and engineer he was interested both in discovering the true nature of the rays and in making useful applications of them. He deplored the haphazard way in which people had plunged into X-ray work, experimenting on themselves and others without proper knowledge of the forces they were dealing with. He felt it his duty to learn and publish the facts.

By long habit he approached the new problem from the theoretical side first and in the next five years covered it more thoroughly than any other investigator save Roentgen himself. Altogether he contributed no less than twenty-eight papers to the technical journals, many of which were reprinted all over the world.

With the help of Lemp and others he set up a large induction coil and began work early in January. He well understood, from the classical experiments of Crookes, Hertz, and Lenard, that the high-voltage discharge within a vacuum tube consisted of a stream of electric particles (later known as "electrons") hurled from the cathode toward the anode at enormous velocity. Like everybody else he had worked with these discharges and had missed the central fact of Roentgen's discovery.

It is interesting to look back on the account Professor Thomson gave of his X-ray experiments, since it is so typical of a great scientific mind at work on the fundamentals of a major problem. In the *American Journal of Roentgenology* he wrote in retrospect:

Many years before, I had obtained a number of Crookes vacuum tubes, exhibiting the effects of so-called radiant matter or cathode rays, but until Roentgen's discovery, it was not known that such tubes gave out any rays into the surrounding space. The phenomena, luminous, thermal and mechanical, were supposed to be limited to the interior of the tubes, or, at least, to be unaccompanied by any radiation into the surrounding space.

Early in 1896 I examined these Crookes tubes to discover, if possible, which form was best suited for roentgen-ray examination, and further, the more important knowledge of what part of or in what condition the interior of the tube was favorable as a source of the rays. In short, I aimed to discover the most effective form of tube for roentgen-ray production. It was soon determined that the place of impingement of the cathode rays was indeed the locus of roentgen-ray emanation. I found among my tubes one in which a concave cathode cup was, as it were, focused upon a strip of platinum at or near the center of curvature of the concave cathode. It was found also that nearly all the roentgen-ray emanation from that tube came from a small heated spot on the platinum strip or plate, and that sharp shadows were produced on a fluorescent screen or photographic plate of the bodies more or less opaque (to rays) exposed thereto. The anode connection, it was found, could be made to the platinum plate itself or to a separate anode terminal within the bulb or tube.

This was his first important observation. Then:

Having at command both static machines and Ruhmkorff coils for excitation, one or the other could be employed for the electric discharges through the tube, as desired, the coil being found, on account of its greater output, more effective. In my eagerness to experiment with this tube, it was accidentally broken down by perforation near the seal and rendered useless soon after it had been operated. (He had crowded so much current through it to produce powerful rays that the glass had melted.)

This was indeed a great loss, as none of the other Crookes tubes were effective in furnishing rays properly directed for experimentation. To remedy this loss I at once set up a Sprengel vacuum pump—after repairing by the glass-blower's lamp the

cracked part of the tube—and in a night and a day the exhaustion, to the high vacuum required, was complete, with this remarkable tube again in service.

In the course of these early experiments certain important facts were discovered. For example, it was found that the rays could penetrate many sheets of sensitized paper, and that shadow images could, on development, be found on each as manifolds. Another development was the production of stereoscopic roentgen pictures, such that in bone fractures and the like, the exact relation of the surfaces of the bones could be seen, and measures taken to secure the precise position and alignment, so that in healing there could be no displacement or deformity. These were produced for the first time early in 1896.

Two separate pictures were taken, one after the other, the tube being held for the exposures in two different positions a few inches apart. The pair of photographs obtained were then viewed simultaneously through a stereoscopic device so as to give the illusion of depth or third dimension. The doctors of the country accepted this new technique eagerly. Eventually it became a standard method for checking up complicated fractures after setting, especially in surgery on the skull.

After successfully demonstrating the stereoscopic process by locating a bullet in a man's chest, the Professor went on with his basic explorations of the X-rays themselves.

The new set of observations concerned the power of the rays to set up secondary emanations in bodies like wood, paraffin, etc. These secondary rays were less penetrating and were radiated in all directions from the body subjected to the initial ray source. I carried these investigations still further and found that the secondary rays would themselves excite still further diffusions which were termed "tertiary."

This discovery played an important part in the protection of roentgenologists from the deadly cumulative burns that ended for so many in death. Long after it was understood that the operator must keep himself screened from the "primary" or original X-rays, doctors failed to realize that a room in which a powerful tube was in operation was filled with secondary and tertiary rays just as deadly after repeated exposure. Severe burns continued until the significance of Thomson's early work was fully realized.

All the early X-ray tubes had an annoying habit of getting "hard" after some hours of use, suddenly ceasing to produce any emanations at all. This was due to the rising of the vacuum within them by bombardment of the air particles by the cathode stream. Thomson's next suggestion was that the tubes be pumped to a very high vacuum indeed and then filled with an inert gas not affected by the rays, which would keep them "soft" enough to stand continual use. The gas-filled tube, with improvements, was eventually adopted everywhere.

One serious difficulty remained to dog the early inventors. The output of X-rays even from the best tubes was exceedingly small, because the induction coils and static machines used to excite them were themselves so inefficient. Only a small fraction of their rapidly oscillating currents flowed from cathode to anode to produce useful rays. The rest was either too weak or was reversed in direction. This low efficiency was responsible for the long exposure times required for satisfactory photographs. What was needed was a "rectifier" to produce steady high-voltage currents in one direction only. Professor Thomson asked Hermann Lemp to try to solve this problem.

Lemp's work with rotary converters gave him a hint. After some time he devised a revolving mechanical switch to be used with a standard high-tension transformer. The switch was to be driven by a motor running synchronously with the alternating-current supply, so that each time the transformer current reversed the contacts were reversed also. The "Lemp selector," as the device was called, produced amazing results. So much current could be poured into the X-ray tube that the metal target was burned up in a few minutes. In fact, it was impossible to use the selector, since no tube could be built that was strong enough to withstand it.

Lemp thought ruefully of the Professor's remark about inventing a thing too soon. Here was a fine example of it. But as there was no help for it, he patented his selector (in the name of the company) and put it aside. Fifteen years later Dr. W. D. Coolidge invented the modern hot-cathode tube with its tungsten target, which bears his name. He needed a powerful source of current to operate it and turned at once to the Lemp selector. Before long hospitals and doctors' offices all over Europe and America were

using the device that the Swiss inventor had so sadly put behind him as unwanted. It was in universal use until a few years ago, when the vacuum-tube rectifier rendered it unnecessary.

During the time that Lemp was struggling with his selector, Professor Thomson, working along similar lines, invented the "dynamo-static machine," which also produced high-voltage direct currents for X-ray tube operation. This was based on Planté's principle of charging a group of condensers in parallel and switching them to the series connection for discharge. Thomson's friend, Professor Trowbridge of Harvard, had built a machine of this type that could throw a single spark 2 or 3 feet long, when operated by hand. Thomson improved on it by accomplishing the switching operation with a motor and transformer so that a continuous shower of sparks could be produced.

The dynamo-static machine was on the whole too cumbersome for commercial application, though it could operate in damp weather, which the ordinary X-ray static machines could not do. It remained idle for years until both General Electric and Westinghouse adopted the principle in creating artificial lightning bolts 5 to 10 feet long.

3

The work of Professor Thomson and hundreds of other brilliant men soon brought the knowledge of X-rays to the point where manufacturing problems were the principal concern. At Thomson's suggestion his company then transferred the work to the laboratory men in other plants, leaving him free to pursue his interests in many other fields. Before he left this fascinating subject, however, he made an invaluable contribution to the art in a warning of the danger of X-ray burns.

After the first few months of intensive experiment scores of investigators and doctors were beginning to notice strange ulcers on the backs of their hands and arms. It was soon realized that the rays were not harmless. But the tragedy was that the nature of their attack was misunderstood. The Professor says:

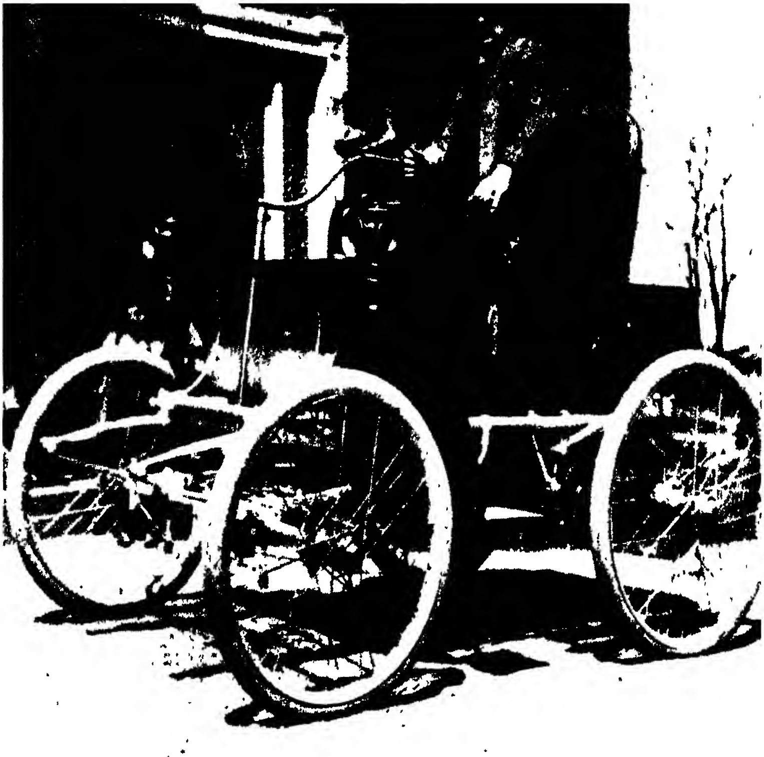
> There were two serious misconceptions in the early days which tended to do harm and to need emphatic correction. It was claimed by some that the roentgen rays themselves were

innocuous and that any injury by them was to be laid to the electric discharges or changes of electric conditions affecting the skin and tissues. It was also claimed and believed by many that tubes excited by static machines, so-called, would not produce injury, while those operated from induction coils were far more likely to do so. These ideas were shared by some authorities who should have known better.

Precautions were accordingly taken against brush discharges by shielding the tubes with thin pasteboard or metal screens and the work went on in ignorance that the real lethal agent was still uncontrolled. Typical X-ray injuries were exceedingly slow in developing their true nature, which was cancerous, and in the meanwhile the eager workers got temporary medical treatment for their ulcerated hands and believed that all would be well. Particularly obscure was the fact that the damage was cumulative. Many very short exposures were just as harmful as a few long ones. So the horror crept upon the investigators and reached an incurable stage before they were fully aware of their danger.

By the middle of 1896 the first of the martyrs had appeared. Clarence Dally, who made X-ray tubes for Edison, began losing his hair and fingernails and suffering from ulcers on arms and hands. Edison realized something was wrong and sent Dally away, then discontinued making the tubes altogether. But it was too late for Dally. He suffered for six years from ulcers, having each treated successfully but always falling prey to another. One after the other his hands and then his arms were amputated in an effort to stop the insidious spread of the disease. But it was of no avail and in 1902 he died, among the first to succumb to an exposure which had lasted only a few months.

The pattern was repeated in case after case. Some died quickly; some lived for years in constant torture. One—Walter Dodd, X-ray technician of the Massachusetts General Hospital—had thirty-two operations but finally succumbed after twenty years. But whatever the suffering, these men were heroic—indeed far more heroic than the military hero of today who does great deeds under pressure of thrill and excitement. For after a very short time all science knew that there was deadly danger in the X-ray, yet not one left the field. Even after the ulcers had appeared these men worked quietly on in their laboratories, hoping only to outwit



Professor Thomson and his first "steam carriage"

death till the job was done. It is in such unselfishness that the true greatness of America is hidden.

During 1896 Professor Thomson engaged in a spirited controversy in the engineering journals with Nikola Tesla, who held that X-rays, being of the nature of light, were harmless. But the case of Clarence Dally got so much publicity because of his association with Edison that the alarm became widespread; several investigators made up their minds to get to the bottom of the danger and publish authentic warnings that could not be ignored.

So many prominent men begged Thomson to throw the weight of his name into the fight that he decided to do so in the most emphatic way at his command.

"I deliberately determined," he says, "to make some crucial experiments upon myself and publish the results. I asked myself what part of my body I could best afford to lose and decided it was the last joint on my left little finger."

Shielding all but this portion of his hand with sheet lead, the most opaque substance known, he exposed the whole to an X-ray tube for twenty minutes, using a static machine as the source of current. Nine days later the unprotected part of the finger had become inflamed and soon shed its damaged skin.

Again, he exposed another finger, this time shielded in sections, part with lead foil, part with sheet aluminum, part with nothing. The result as before was that the lead-protected skin showed no burn while the other two portions did. The use of the aluminum, opaque to electrostatic effects but like glass to X-rays, once and for all put an end to the notion that brush discharges were to blame and proved that X-rays were dangerous, regardless of their origin.

In the next twelve months the Professor published descriptions of his tests and injuries in four separate communications to the technical journals. Authorities everywhere were quick to express their gratitude and it was widely rumored that Thomson was suffering from burns that would presently become fatal. Fortunately this was not so. Providence or a tough constitution had saved him from the deadly march of cancerous growth, and no further ulcers appeared. But for the rest of his life the two fingers were scarred and stiff and a source of constant annoyance. It was particularly obnoxious to him when friends called his injury acci-

dental. He asked no credit for what he had done but objected to the accusation that he had been careless.

Thomson's explanations of the X-ray danger were widely heeded, for no one doubted his authority. Combined with the warnings of other equally courageous men, they gradually induced all workers in the new field to take refuge behind heavy lead screens. When this proved impractical a special form of lead glass was adopted for tubes and eventually the smaller X-ray outfits for doctors and dentists were immersed in lead-lined tanks of oil.

Yet it was many years before the rays became entirely safe. While harmless to the patient when expertly given, even in large doses, they could still be fatal to the doctor in repeated small amounts. That is one reason why, even today, the dentist always insists that his patients hold the little X-ray films in their mouths themselves. An exposure of even a few seconds a day might ultimately end in his death.

Chapter 20

I

At the height of the X-ray excitement came the announcement of another great victory over nature. In the summer of 1896 the young Italian electrician, Guglielmo Marconi, came to England to demonstrate practical wireless telegraphy to the British postal officials. After several discouragements he was able to transmit messages two miles across Salisbury Plain. The demonstration was immediately followed by a successful crossing of the Bristol Channel, and Marconi formed the Wireless Telegraph and Signal Company to exploit the invention.

Though the Italian's brilliant work earned him the popular title of the Father of Wireless, the principles behind his invention had been known for a long time. Joseph Henry had produced distant currents by induction at Princeton in 1832. Faraday in that same year had expressed the basic concept of the electromagnetic field, which traveled outward in all directions from its source to infinity. James Clerk Maxwell later reduced this concept to mathematical form as the theory of electromagnetic waves, and showed that it *should be possible*, with apparatus yet uninvented, to send and receive etheric signals. When Maxwell's theory was accepted in the seventies, all electricians agreed that wireless signaling could be done and would be eventually if the need should arise. They doubted, though, that it would come for a long time.

In 1871 and again in 1875 Elihu Thomson actually did transmit and receive wireless impulses through a hundred feet of masonry and air, being the first in the world to do so. He and his friend William Greene agreed that messages could be spelled out by this means, probably for distances of several city blocks, with the clumsy apparatus at hand. But they saw no advantage to it then. Telegraphy by wires was still quite adequate to the world's needs.

Little was done thereafter until the young German physicist Heinrich Hertz in 1887 confirmed Maxwell's theory by actual

experiment. Hertz was in no way interested in practical wireless signaling. His only desire was to broaden the base of general knowledge by showing how the mysterious "ether" transmitted Maxwell's waves—heat, light, and electromagnetism. It is possible that Hertz would have accomplished practical signaling himself if he had not died, when only thirty-eight, on the eve of the final victory. However, his work was essential to the invention that Marconi soon made. And in point of scientific value it was equally important, since it furnished the background for the wave theory so fundamental to modern physics.

Hertz's earliest experiments consisted in producing by spark discharge a train of electromagnetic waves, then detecting them in distant parts of the room by a loop of wire and sphere gap—the Hertz "resonator." He then went on to study the behavior of the waves, showing that they could be reflected and refracted like light, and traveled at the same high speed.

Professor Helmholtz made the first announcement of Hertz's work in Berlin, claiming it to be one of the greatest discoveries in scientific history. Helmholtz's tremendous personality and his eminence in science lent such force to his endorsement that all the world listened; hundreds of investigators in Europe and America turned their attention to the new "Hertzian waves," among them Michael Pupin, who was studying under Kirchhoff in Berlin at the time.

Practical wireless was very close now, but there were still nine years of painstaking research to be done.

During these years Professor Thomsons was concerning himself with alternating-current transformers and machines and with the novel effects of magnetic repulsion. Without directly entering the field of Hertz's experiments, he found time to investigate a hidden world of his own discovery—the phenomena of high-frequency electric oscillations. In 1890 he patented a new type of dynamo which produced 5,000 alternations a second, and soon afterward a "high-frequency transformer" without an iron core, which gave sparks with millions of oscillations per second. It was this last that Nikola Tesla some years later reinvented and named after himself. Thomson-Houston exhibited in Chicago in 1893 a transformer of this type which, as already mentioned, gave sparks 64 inches long.

Professor Thomson's primary purpose in these inventions was to make a fundamental study of high-frequency discharges in order to see what new characteristics if any would be possessed by alternating currents of enormous rapidity of change. He did not know at the time that he was laying the groundwork for wireless and more especially for short-wave radio, still so far in the future. But he was thoroughly familiar with Hertz's researches and realized that any new basic knowledge was bound to be useful.

He soon discovered effects of great importance with the high-frequency transformer. The ordinary laws governing common alternating currents no longer held. The electricity refused to follow around sharp turns; passed through small coils it jumped from turn to turn in short circuit. In what was later called the "skin effect," it insisted on traveling on the surface of conductors only. And it was extremely sensitive to electrical "resonance."

Still another ramification of Thomson's studies was the invention of the "singing arc"—a method of obtaining heavy currents at high frequency by a combination of a carbon arc and resonant circuits. The importance of this was that it produced its results from a direct-current power supply and hence indicated a new way to change from direct to alternating without rotating machinery.

The harvest from these early plantings has been great, though Thomson claimed no credit for any of them. The whole science of radio communication is based upon high-frequency oscillating currents and upon the phenomenon of resonance, or "tuning," which Thomson had observed as far back as 1876. Early radio telephony employed the singing arc for its continuous-wave transmission, under the name of the "Poulsen" and "Duddell" arcs. These men began where Thomson left off. For many years after transoceanic wireless was begun it was operated entirely by high-frequency alternators developed from Thomson's first model. And the "lightning generator," which Steinmetz made famous in 1922, was only an outgrowth of the high-frequency transformers and circuits originally set up in Lynn.

One of the most suggestive results of this whole period of the Professor's work was the curious physiological effects of currents of extreme frequencies. It was possible, Thomson found, to pass a full horsepower of energy through his hands and arms at hundreds of

thousands of volts pressure, with no other effect than a slight sensation of heating at the wrists. A tiny fraction of this energy would have been instantly fatal at low frequency.

The reason, he understood, was that the new currents stayed near the surface, where there were no important nerves to be damaged. Some years after his experiments, high frequency began to be used in medicine and today it has found important applications in diathermy and the production of artificial fevers and in the "electric knife" for surgical cautery. This last Dr. Harvey Cushing attributed to Thomson himself, though he had made no claim to its invention.

The Professor would be the last today to want his name credited with so many achievements simply because he had done early work in the radio field. It is true to say, however, that the example of his clear, logical thought and the association of his name with electrical phenomena which were then little understood spurred many others on to make the actual applications.

During all this period Thomson, Tesla, Sir Oliver Lodge, and others kept up a vigorous though amicable stream of argument in the columns of the electrical journals in England and America. As was his wont the Professor preferred to try the case in print rather than in court. For years after, he continued to discuss wireless, just as he did the X-rays and electricity in general, scotching many a specious argument and false claim by simple statement and clear proof. He had no need to go to court; in the eyes of science he *was* the court.

2

In the year 1894, when the scientific world had become thoroughly acquainted with the researches of Hertz, Thomson, Lenard, and others in electrical discharges, Sir William Crookes rang up the curtain on practical wireless telegraphy with this statement:

> Rays of light will not pierce through a wall, nor, as we know only too well, through a London fog. But the electrical vibrations of a yard or more . . . will easily pierce such mediums, which to them will be transparent. Here, then, is revealed the bewildering possibility of telegraphy without wires, posts, cables, or any of our present appliances.

The occasion of this prophecy was the invention, by Professor Branly in Paris, of the metal-filings "coherer," or detector for electromagnetic waves. In the next two years a great surge of interest in Hertzian-wave telegraphy swept through the laboratories of Europe. Such men as Kelvin, Sir Oliver Lodge, Professor J. A. Fleming, and Sir William Preece all explored the field—but were unable to take the final step to success. When Marconi, scarcely twenty-one, appeared among the sages of England with a space telegraph that actually worked, no scientist was surprised. Preece remarked wryly,

"We all knew the egg, but Marconi showed us how to make it stand on end."

The solution was so simple that everyone recognized it at once and rejoiced that it had been found. Marconi lacked their profound knowledge, but he possessed a genius for simplification which carried him over the wilderness of complications and set him firmly on the heights.

Marconi's basic patent was amazingly simple. It merely showed two Hertzian-wave oscillators or loops, set at a considerable distance apart. One side of each loop was connected to ground; the other side was joined to a vertical wire raised high in the air. It was this unique addition of ground and aerial which allowed signals to travel over long distances and be detected. The rest of the arrangement had been intimately known to science since 1887.

This was the patent which made Marconi a world figure equal to Edison.

The original apparatus as Marconi set it up in England was very crude. Its rapid success came from the use of the Branly coherer in place of the Hertzian loop as a receiver and from the addition of many other brilliant ideas quickly offered from all sides. Once the fundamental principle of the aerial and ground wires was established, the whole accumulation of prior knowledge was brought to bear and progress was swift and sure. It was a beautiful example of the "great invention," which the public in its innocence believes has sprung full-fledged from the brain of a single man. Actually, the invention of wireless had been begun by Franklin a hundred and fifty years before.

From 1896 on, steady advances were made in England while the world looked on with skeptical interest. Intense competition

presently developed in wireless as it had in X-ray work, and before long the usual patent complications had begun. The use of the tuned-circuit principle brought Pupin into court, for he claimed to have discovered it in connection with his telephone "loading coil," just then making him rich. At one time Edison was involved in the controversy. His discovery of the "Edison effect" in the incandescent bulb was the forerunner of Professor Fleming's invention of the vacuum valve and De Forest's audion. But it was only De Forest who pressed the claims of priority.

In common with many other scientists, Professor Thomson saw his ideas borrowed, reinvented, and applied. But he made no attempt to interfere. He genuinely admired young Marconi and saw no use in retarding progress with patent suits.

In the long run the wireless art was remarkably free of the confusion and bitterness that had beset the electric light. In part this was because Marconi's patent was so strong that he was able to control the development with a single company, as Bell had done with the telephone. But in the main the reason was personal. Everybody loved and admired this youthful Italian who drove on toward his goal with such outstanding courage. His was the spirit of the new century, to which the older men quietly bowed their heads.

By the year 1900 Marconi had spanned the English Channel and could signal 200 miles without wires. Now he proposed to jump the Atlantic, bridging a gigantic gap of 2,000. The most sanguine of his scientific backers thought him crazy, all but Professor Fleming, who, as chief engineer of the company, had to design the apparatus to make the test.

Late in the year the long lines of high wooden masts with their aerial wires were put up at Poldhu, Cornwall, and Marconi came to America to establish a receiving station on the bleak coast of Newfoundland. He did not succeed; gale after gale blew his wires down. Fleming was in England faithfully pouring signals into the air every day, waiting for Marconi to cable him it was no use.

Winter was coming on and the young Italian was desperate. He was sure the signals were streaming in from the sea, but he could not capture them without a high aerial wire. What he did has been described elsewhere by the author in these words:

If he could not stop the wind he would outwit it. And so he fastened his aerial wire to the tail of a kite which was borne furiously upward on the winter gale. With what pounding of the heart must he have watched his little coherer attached to the lower end of the wire! Like Franklin, he was determined to steal from the clouds another great secret of electricity. All at once the filings in the coherer stiffened. Something was coming—yes, it was Fleming! Faintly, almost too faintly to be understood, came the letter "S" of the Morse code: S-S-S; then again S-S-S. Marconi had won. The pressure of Fleming's hand upon a key had been heard two thousand miles away across the ocean.

News of this latest triumph of science caused less of a public reaction than the feat deserved. Enthusiastic as the scientists were about the young Italian, they simply did not believe that he could have sent messages across the Atlantic. However, a few of the less conservative engineers and businessmen of New York decided to give Marconi a banquet to celebrate his achievement. On attempting to make the arrangements they were deeply chagrined to find that most reputable scientific men refused to be present. It was said that Marconi was a faker in the class with Dr. Frederick Cook, who had recently been caught in a deception about climbing Mount McKinley in Alaska. Signaling across the Atlantic was held to be impossible because electromagnetic waves, like light, could not follow the curvature of the earth. Sent out 2,000 miles from England, they would cross the region of Newfoundland 200 miles in the air.

T. Comerford Martin, editor of the *Electrical World*, was in a dilemma, for he had already given the dinner a lot of publicity and was eager to make it a success. So he appealed to Professor Thomson, urging him to endorse Marconi's claims. The Professor, almost alone in the engineering fraternity, believed that wireless waves followed the contour of the earth and saw no reason to doubt Marconi's achievement. He wrote Martin that he had perfect confidence in the Italian's claims.

Thomson's opinion was quickly spread about in New York, and the timid dinner guests agreed to appear. The reception of the youthful inventor became an ovation. Years afterward Martin told Thomson how grateful he was for the service he had done. He

said with a grin that the Professor had saved a lot of important people from showing themselves up for fools.

Marconi was the Professor's firm friend and admirer ever after.

3

Amid all the excitement of the two great electrical discoveries, Professor Thomson pursued his way much as usual, adding new inventions to his long list, speaking and writing constantly on electrical subjects. He and Lemp had a dozen different projects on the fire at once, all of which had an important bearing on the times. One of these was the automobile.

Because the trolley car had developed a very compact electric motor Thomson decided to build an electric automobile first. Lemp made the designs, departing from those of other early inventors by placing the heavy storage batteries in an underslung box in the middle, to keep the center of gravity down. The first machine was ready to run in July, 1897, and Lemp proudly invited Walter Fish, the plant manager, out for a ride. They chose the late evening when the Lynn streets would be clear and spectators few. It was well. After riding a considerable distance the drive pinion broke; Lemp spent most of the night locating a horse and getting the experiment home.

But the "electric carriage" soon lost the Professor's interest. It was too tame and too dependent on the home charging outfit. "It is like a calf," he said. "If you move it you have to take the cow along too." So they switched to the steam carriage just then coming to popular notice.

The Professor turned his own hand to the design this time, producing the "uniflow" engine in which the steam exhausted through special ports at the bottom of the cylinder instead of through the intake ports. This prevented the cooling of the new steam and improved the efficiency so much that the design was patented for general use. A minor annoyance followed when a German firm pirated the invention and sold many of Thomson's engines in Europe under the bogus name of "Unaflow."

The boiler for the vehicle was also new—of the "flash" type, made of a steel tube coiled up, without the conventional large storage drum for the steam. Thomson felt that this was an essen-

tial improvement, as any quantity of live steam under pressure would be too dangerous in the hands of laymen.

Lemp contributed the nonreversible steering linkage and the internal expanding brake; the new carriage was built and became an immediate success. Steam enough to start it moving could be generated in about ten minutes. The torque on the rear wheels was so violent that once, going up a steep hill, the carriage reared up and stood on end, dumping Lemp out on the back of his neck. But he was used to this kind of treatment from new inventions. Edison's first electric locomotive had thrown him, then backed and run over him. And when Edison had shouted "Lemp, are you killed?" he had been able to answer that he was all right.

The General Electric began building steam carriages in a modest way and Thomson himself drove to work in one for many years. Eventually the most valuable patents were sold to other concerns that were making a specialty of the automobile. One of these covered an electrically welded boiler. Joints could be made so tight by this means that a Thomson boiler was known to have held air pressure for ten years.

The sudden gathering of war clouds in 1898 found the Thomson Electric Welding Company once more on its feet, thriving and looking for new applications everywhere. A novel and important use of welding came out of the emergency.

For the past two years the United States Navy had been building two great new battleships, the *Massachusetts* at the Cramp yards in Philadelphia, the *Oregon* at the Union Iron Works in San Francisco. These were to be the first warships in the world to carry the latest hardened steel armor on turrets and hull—provided that the armor could be installed.

Lemp at the time was trying out an idea for an electric torpedo, to be powered by a cable unreeling behind it as it went. He was spending his evenings rowing about Lynn harbor retrieving the torpedo after false starts. When he got home one night he read in the paper that the Navy was having such a bad time drilling holes in the Harveyized armor plate that it was feared the two battleships would not be commissioned in time to enter the Spanish War if it came. It was taking a skilled machinist sixteen hours to drill one hole 2 inches deep. Last minute changes in design made it

impossible to cut the holes before the steel was hardened. And the armor was so thick that annealing it locally with the acetylene torch had failed.

It flashed through Lemp's mind that the Thomson welding machine could apply such an intense heat to one spot that annealing would be easy. He took the suggestion to the Professor, who was so impressed that he wrote the Carnegie Steel Company asking for a sample of Harveyized steel for experiment.

When the chunk of armor plate arrived it proved to be a piece weighing over 100 pounds. Lemp, who was a small man, lifted it with misgivings. The only welder big enough to heat it was at work on a trolley track in Boston and could not be used for experiment except at night. So Lemp took the sample in his arms and staggered into the city late that afternoon.

There he softened several spots for drilling and took it home. Next day the steel was as hard as ever and broke every drill used. He tried to figure out what was wrong, then suddenly realized his mistake. The armor was so massive it chilled instantly the current went off, and hardened itself again. For proper annealing the current must be tapered down gradually. Lugging his burden back to Boston a second night, he tried this out and found that it was a complete success. In the softened spots holes could be drilled in a matter of minutes.

Thomson got in touch with Admiral Sampson of the Bureau of Naval Ordnance in Washington, and President Royce of the welding company took Lemp's sample down to show him. Sampson was delighted and agreed it might save the day for the two battleships, if only the procurement of the necessary special welding machines could be jammed through in time.

"Why not?" cried Royce. "We'll build them and you take delivery. The details can be settled later."

"It's no good," Sampson told him. "The Navy never orders equipment that is not already advertised on the open market. You'll have to send down specifications and make us a bid on the usual forms. There will probably be no competitors and with my recommendations it ought to go through in about three months."

When Lemp heard this he was furious. Did the Navy think the Spaniards would wait for official red tape to unwind? So he went ahead and built the welders anyway, at the same time sending the

plans to Sampson. As good as his word, the admiral got the order through in just three months. The machines were ready and waiting. And now the Navy, in a sudden burst of speed, backed a special train into the factory at Lynn, loaded the welders, and took them to the shipyards by express.

The Thomson-Lemp softening process did all that Lemp claimed it would, and the *Oregon*, at least, was completed with its aid. She sailed clear around the Horn, and arrived at Santiago Bay in time to help drive the Spanish fleet onto the beach.

Later on, Lemp and Royce went to London, where they found that the Royal Navy had given up using hardened steel gun turrets altogether, because of the impossibility of cutting last-minute holes. After another long battle of red tape the welders were accepted here also. The Lemp process was used in the British Navy for many years and not discarded till newer armoring methods allowed the drilling of holes in large pieces before the steel was hardened.

Professor Thomson took no other professional notice of the war. But personally it had a grave effect upon him. During the critical months of what the British misnamed the "Yanko-Spanko War" the coast of New England was considered to be in great danger of shelling from the Spanish fleet, and many people closed their houses and moved inland. Steady-minded as the Professor was, he judged the danger to be imminent enough to follow suit. So he quickly uprooted his whole household, including his wife and children, who now numbered four, and sent them to the town of Middlesex Fells, well removed from the shore—a point he considered quite safe from Spanish bombardment.

He traveled back and forth to Swampscott and Lynn all that summer and took to bicycling a good deal. One day, trying out a tandem machine with a friend, he got his signals mixed and fell off and broke his ankle. It was one of the few casualties in Massachusetts due to the Spanish War.

I

Chapter 21

One day near the turn of the century a small party from General Electric went to the railroad station in Lynn to meet Charles E. Tripler, a research man of growing importance. The party included Professor Thomson, E. W. Rice, works manager W. C. Fish, and Hermann Lemp. Tripler was coming up from New York to demonstrate the extraordinary properties of liquid air.

Professor Thomson was keenly interested in the low-temperature investigations of Fleming and Dewar at the Royal Institution. Faraday himself had begun the work on extreme cold in that same laboratory seventy years before. Now Dewar had pushed his experiments within a few degrees of the south pole of absolute zero. He had reduced hydrogen itself to liquid form and had made exciting discoveries in the electrical behavior of metals in that heatless realm where conditions were almost those of outer space.

"It is a well-recognized principle," said Karl T. Compton in 1925, "that one of the most fruitful methods for studying any object is to disturb it and then see how it behaves." Dewar and Fleming had so violently disturbed the normal temperature pattern found on earth that they had opened a complete new region for exploration. One of Professor Dewar's minor achievements had been the invention of the double-walled vacuum flask for the storage of low-temperature products. We know it today as the "thermos bottle."

Tripler's contribution to the production of cold was an apparatus in which expanding compressed air chilled itself in progressive stages until its temperature fell to about −300 degrees Fahrenheit and it became a liquid. The new field fascinated Thomson because it offered that combination of pure science and practical engineering in which he was most at home. He was anxious to have the company buy the machinery to make its own liquid air for laboratory experiment.

Tripler alighted from the train with a three-gallon milk can filled with the chilly fluid. He had been traveling for nine hours and had lost only a third of it by evaporation. This magic he said he had accomplished merely by wrapping the can with heavy felt. He took out the stopper and showed his hosts the bluish liquid lazily steaming inside its container. Though it had the potential energy of so much nitroglycerine, it looked as impotent as a can of watered milk.

Eagerly plying him with questions the quartette led him to a restaurant in Central Square to have lunch. The milk can went under the table at Tripler's feet.

As soon as they were settled the inventor said, "Now watch. I will show you something." Quickly he speared a butter ball with his fork and dipped it in the liquid air. When the waiter came he said, "See here, what is the trouble with this butter?" And he dropped it on the plate, where it shivered into a thousand pieces. The waiter stammered an apology and hurried off to get some more.

The Professor was delighted. This was like the old days in New Britain. "Now let me try something," he said. When the steaks were on the table he sneaked Tripler's piece into the liquid air, bringing it out as hard as iron. Summoning the waiter he adopted the air of a man whose trusted employee has betrayed him and said, "Waiter, is this the kind of steak you serve me when I bring distinguished guests to your restaurant? Look!" He picked it up and dropped it with a bang that smashed the plate to bits. "Now, take this meat back and bring the gentlemen a properly cooked piece."

The waiter muttered something about "these crazy scientists" and did as he was told, returning only to find that they now objected to the bread. Rice crushed a piece in his hands and blew it away like dust. But when he started to scold, the waiter ran to fetch the proprietor. It was too much for him.

By the time the proprietor arrived the four were getting into their coats.

"Gentlemen," he cried, "if you will just wait a few moments, everything will be made right. I cannot understand. . . . "

Thomson cut him short and the party trooped out, doing its best to keep a straight face. The waiter moodily began to clear the table.

"See what you have done!" cried the proprietor. "Professor Thomson will never come here again. You're fired!" He picked up a cocktail that had been left half finished. It bounced onto the table, a solid block of ice.

"I tell you they were magicians," growled the waiter, turning away.

And so, indeed, they were. But the Professor went back later and made sure that the little prank was explained.

Liquid air made by Tripler's process became a stand-by in the General Electric and many other laboratories. It was invaluable for obtaining high vacuums and for other research uses. Professor Thomson studied its properties thoroughly and wrote an article about it the following year, predicting that its tremendous stored energy might be valuable in war. He suggested it for driving submarines and torpedoes, as a propelling charge for big guns and as a high explosive for shells and bombs.

At least one of these predictions may have come true, in the German submarine which is said to operate under water on stored oxygen and hydrogen instead of electric motors.

Thomson said in 1899:

> Submarine boats . . . may yet find use for liquid air. It can be stored without pressure and can be evaporated at any desired pressure, while its bulk represents that of air under 800 atmospheres (12,000 pounds per square inch). A storage battery would probably be from five to ten times as heavy as liquid air in a receptacle for equal available energy. But no storage battery could be discharged at an equivalent rate.

It is thought that the storage of propelling gases on the German U-boat may be accomplished by liquefaction.

2

As the new century came over the horizon science and engineering looked with pride upon the progress they had made. The most productive hundred years in history had opened a world of unlimited possibilities in material welfare and social advance. Time and distance had been telescoped; nature had been forced to yield huge stores of energy for doing man's work. New tools, new processes, new modes of thought were building a new kind of civilization. The year 1900 was a moment of magnificent hope.

Visit of Lord and Lady Kelvin to the United States, 1897 Professor Thomson and Dr.

The tight little world of the "natural philosopher" had burst. The accumulation of knowledge and of technical skills was scattering the earth with specialists. The lone inventor and mechanical genius were yielding first place to great organizations of engineers. The work of applying nature's forces to useful purposes was no longer haphazard or experimental; it had become a well-established art.

The application of electricity to lighting, to the transmission of power, to mining and smelting, to transportation and communication and medicine was no longer a dream; it was a commonplace. The world had ridden in its first automobile, had listened to its first phonograph, seen its first motion picture, shuddered at its first practical submarine. It had already laughed uncertainly at the flying machine; it had looked with wonder on an engine that burned powdered coal. It had eased its pains with aspirin and quieted its parental terrors with dyphtheria antitoxin. The phrase "modern miracle" was losing its glamour. Mankind had accepted nature as its slave.

And yet men of vision knew that the march had scarcely begun. Though engineering had settled down to the prosaic work of application, science had been born anew, with a life of untold excitement ahead. In its shining new kit science had the tools to cut its way out through the wilderness in endless campaigns of exploration. George Hale and his astronomers had opened the laboratory of the sun, the planets, and the stars; Michelson and Morley, in measuring the velocity of light had given a new meaning to the ether; Kirchhoff and Bunsen had provided general physics with the invaluable new tool of spectroscopy; J. J. Thomson had indicated the construction of the atom; Becquerel and the Curies had given chemistry new meaning with their researches on the radioactive elements; Gibbs, Maxwell, Kelvin, Lorentz, and Fitzgerald had furnished them all with new mathematical weapons to fight their way.

No worker among them but was proud and inspired by what had been done, but all were humble too—humbled and mightily awed by what was ahead. That which had been accomplished was great; but the promise of the future was greater still. A huge responsibility rested upon them and upon their descendants in science. The opportunity was limitless; what they would make of it

depended only on their capacity to increase their vision and understanding as the way became steadily more complex.

As Elihu Thomson stood on the threshold of the twentieth century at forty-seven he faced a decision. Should he remain with engineering to develop and apply the things he had already discovered? Or should he, like science, go forward into a new world? The answer was there waiting; it had been formulating in his mind for the past ten years. He would go forward. As he had had to prepare for readjustment when he left Philadelphia for New Britain, so now he must prepare for it again, forsaking little by little his intimate connection with electrical application, putting in its stead a growing duty toward the world of pure research.

From this moment on he was to be an elder statesman of science, a consultant rather than a practicing engineer; a teacher and philosopher rather than an inventor. All the technical world would come to him for guidance and advice. His influence, though subtle, would be profound. Less and less would there be opportunity for public acclaim; more and more for quiet, unselfish service.

Now indeed he was to leave Edison behind. For while the great inventor had little left to give but the glamour of his name, Elihu Thomson's greatest contribution was before him. Throughout his remaining years he could pour his wisdom and his inspiration upon all. His was to be the role of general consultant in science, his the privilege of attaining that timeless quality so rarely the possession of men.

The physical change in his life was very little. He remained in Lynn as before, lived and worked in the same places, saw the same kind of people, enjoyed the same friends. He had struck no bonanza of fame but had been thrust up gradually, like a mountain rising imperceptibly through the earth's crust, until he stood on the sky line of science and quietly dominated it.

Indeed his influence was remarkably like the subtle power of a mountain, standing firm above its fellows and above the rugged valleys and foothills of science—silent for the most part yet shaping the route of every traveler.

The Professor's little office became the focal point of all the great men who visited the plant—Edison, Steinmetz, Kelvin, Silvanus Thompson, Ayrton, Stanley, George Hale, Elisha Gray,

Westinghouse, Colonel Crompton, Arthur Kennelly, and many more—and, too, the haven of hundreds of lesser men to whose problems he was always ready to devote his time and energy.

That small office is there yet, a museum reverently preserved by John A. McManus, his faithful secretary and patent assistant. Its furniture is tagged with brass plates explaining how the Professor used them; its very electric-light bulbs and welded andirons are the same as they were in his day. Two big roll-top desks, a broad table, the marred safe that Lemp burned open, a few stiff-backed leather-seated chairs, a dingy view of the back yards of Lynn where Van Depoele practiced with his early trolley cars—these were the modest working quarters of the dean of American electrical science.

Steinmetz was one of the most constant visitors in the early years of the century. He used to come in of a morning early to argue a problem of design. He would perch himself on top of the larger roll-top desk and put his feet down among the papers and then talk, his long black cigar bobbing up and down, accentuating every word. Though the Professor was unimpressed by personal idiosyncracies, he loved to watch this man's mind leap to some lofty new height, catch there, and swing itself firmly onto new ground without apparent effort. The cigar was legendary. Thomson did not like the smell of it but knew he had to put up with it. Steinmetz had once calmly walked out of the Schenectady laboratory and refused to return because the management had put up a No Smoking sign. "No smoking, no Steinmetz" was his message to the plant.*

In this office Steinmetz first proposed liquid air for company use; here he and the Professor talked for many hours about lightning and the protection of alternating-current lines from its depredations. Most important of all, in this modest little room it was that Thomson, with Steinmetz and Rice, developed the idea of an industrial laboratory for pure scientific research.

Steinmetz and A. G. Davis, the company's patent head, had originated the scheme and proposed it to Rice. Twenty-five years of intimate association with Thomson had shown him that basic

* This anecdote has been published and denied many times. It is no more unlikely than many other things "C.P." did and is certainly characteristic of this unconventional genius of the laboratory.

scientific knowledge was indispensable to commercial success. Many times he had heard Thomson forecast the moment when scientific principles already found would become barren, when progress would lag until new discoveries infused new blood. So now, with Steinmetz, Rice had come to Lynn to set before his old professor the idea of pure research backed by industry.

Why should we not, he asked, open a company laboratory exclusively for exploration? A laboratory where trained scientists might ask whatever questions of nature they could devise? Let this group be free of commercial pressure; let its members follow their own scientific curiosity whither it might lead.

For the first time in history let the discoverers be subsidized by adequate funds so that they could do their best work. Free of competition, free of the pressure for production, free, indeed, of the urge to reach any practical end at all, let them seek knowledge for its own sake and at their own pace. "If we choose our men properly," he said, "we can't fail to have practical results."

Professor Thomson at once saw the wisdom of the suggestion and gave it his strong support. His own interests were rapidly swinging toward pure science in search of building materials for future engineering structures. Research, in his view, was fundamental.

The scientists of Europe had long known that modern invention, feeding upon the reservoirs of fundamental discovery, would soon drain them dry if they were not constantly replenished. James Clerk Maxwell, as the founding director of the Cavendish Laboratory at Cambridge, had created the first great instrument in England for this replenishment. In Germany, too, Helmholtz, Kirchhoff, Bunsen, Hertz, and many more had by their example shown the wealth of useful results which followed laboratory exploration in the theoretical sciences.

John Tyndall had come to the United States in 1872, ostensibly to lecture on light, but more especially "to show the uses of experiment in the cultivation of natural knowledge." He had argued passionately for the experimental method and was, in truth, the father of pure research in America.

But it had been a hard lesson for this tough young world of the pioneers to learn—a world that had consistently worshipped the practical and that loved to make gods of inventors like Edison.

America in 1900 was driving ahead blindly, expending its resources without a care for their exhaustion. By the end of the century its boisterously competitive engineers had rendered it well-nigh bankrupt in scientific background.

Both in Europe and America the work of pure research was confined to the universities and learned institutions, notoriously hampered by poverty and by conservative ideas. Men like Rowland in physics, Norris in chemistry, and George Hale and Percival Lowell in astronomy worked alone, much of the time at their own expense or plagued by their duties as teachers in the universities.

Exploration—the most important element in the future fabric of a mechanical civilization—was being left to chance.

Professor Thomson needed no urging toward the scientific Utopia offered by Rice and Steinmetz. It was the embodiment of his own dream. "When you are ready," he said, "I can suggest some useful directions in which to proceed."

"But," protested Rice, "you must organize the new laboratory yourself. There is no one else." The Professor, he pointed out, had always been the research leader of the company—the trail blazer, the man of ideas. This was the very opportunity he had sought all his life.

But Thomson was listening to another voice—a voice out of the future, calling him to freedom. His instinct told him that he must not subordinate himself, even to this magnificent undertaking.

He refused them gently but firmly. He was too old, he said. They must have a young man, who could grow up with the project. Furthermore, the laboratory must be opened in Schenectady, side by side with the main factory of the company. He could not go to Schenectady. His home, his friends, his interests—his roots—were in Lynn. He loved to be near Boston, to join in the monthly meetings of the scientists and other groups at which he held forth regularly. And, most important of all, he did not like administrative work and was not suited to it.

This was the parting of the ways, the moment when Elihu Thomson assumed his role of adviser, leaving that of participant behind. The more his friends urged him, the more unyielding he became. "My value to the company is very restricted now," he told them. "I'll stay where I am and do the work I have always intended to do."

So that was the decision. Rice accepted it sadly, but with understanding. Long experience told him that the Professor's judgments were right, no matter what arguments were brought against them. He returned to Schenectady to persuade the company directors that even without Thomson's administration this industrial research scheme must be tried, if the future was to be secure.

For the time being, Steinmetz agreed to take the lead himself. The company had already built him a small laboratory for his personal use and here he ensconced himself and began research work in addition to his duties as chief mathematician. He had been there only a short time when he invented a new type of arc light using rods of magnetite and copper instead of carbon. This proved to have so much greater efficiency than the old style of lamp that it quickly replaced it and is still in use today.

But Steinmetz was too much of an individual to make a good executive. It was evident to Rice that the Research Laboratory would remain a one-man show as long as the brilliant little German was in charge. So he invited Willis R. Whitney, a young chemistry professor at M.I.T., to come to Schenectady to take on the job. At first Whitney demurred. He was deep in a research on colloidal solutions and hated to give it up, even for this great opportunity. He asked his friend Professor Thomson what he should do. Thomson told him to accept the offer by all means. Steinmetz would be there to guide him and there were no limits to the explorations ahead.

"I should rather have your guidance than his," said Whitney.

"Very well," Thomson replied. "Make a beginning; I will come to the laboratory once a month for a talk."

Whitney began his work as modestly as young Thomson had done thirty years before, in the carriage house on Steinmetz's estate, but soon moved to a laboratory of his own at the plant. From the beginning industrial research proved to be a success. One of Professor Thomson's first suggestions was that the efficiency of the incandescent lamp should be improved. Only a few per cent of the electric power went into light; the rest was lost in heat. Enormous gains for maker and consumer would result if a better material could be found for the filaments.

Whitney took the hint and started his men on a search that

occupied many years. The first practical discovery was the metallized carbon filament, which resulted in the "Gem" lamp. This quickly replaced pure carbon everywhere and became the standard until W. D. Coolidge, Whitney's young assistant, made the discovery of "ductile" tungsten, which proved to be the ideal filament material. It had far longer life than carbon and gave several times the brilliancy of light with a large gain in efficiency. Tungsten itself was of course not new, but Coolidge's method of making this hard, brittle metal as tractable as steel was a major advance in technology. It was ductile tungsten that put the electric light within reach of all the world.

In the search for better light the pursuit of pure science had been justified again and again. Tungsten quickly revolutionized the X-ray tube and opened up new possibilities in chemistry and metallurgy. Studies in electric discharges in a vacuum, which were offshoots of the tungsten research, brought the modern radio tube and television, as well as large advances in telephony and the motion-picture art. The whole field of chemistry and physics was immeasurably the gainer from the general knowledge that had been acquired.

Under Dr. Whitney's leadership important advances were made in almost every branch of the physical sciences. Discoveries included such diversified things as chemical plastics, new forms of insulating materials and ceramics, new alloys of steel and other metals, better lubricating oils—all of them the practical results of researches begun purely for the sake of broadening scientific horizons.

But greater than the value of any one discovery was the long-range influence upon science and upon the general progress of the mechanical age. This laboratory was the symbol of the new era; the end of isolated discovery and the beginning of scientific teamwork. The accumulation and codification of knowledge had now become a necessary preliminary step to every practical advance. Edison's day of headlong attack by trial and error was gone.

The ultimate purpose of science, as Thomson and Whitney saw it, was to improve man's utilization of his physical environment. In this new idea of organized research lay a priceless opportunity to realize this great goal.

The example of the Schenectady laboratory was soon followed

by large industries everywhere, and gradually by the universities and private foundations as well. Today science advances mainly through the teamwork of many minds and the careful pooling of many special skills. In chemistry, in physics, in electricity it requires the utmost energy of an army of men and tremendous aggregations of money and equipment to push even a little farther into the unmapped wilderness that is all around us. Paths of discovery are no longer as easy to find as they were in Faraday's time.

America could have done no greater service to mankind than to energize this new spirit of pure research. Elihu Thomson was one of the few who foresaw the need when he urged Whitney to make his insignificant beginning in the carriage house on Steinmetz's estate.

I

Chapter 22

For the first few years of the Research Laboratory's existence the Professor faithfully traveled to Schenectady for the monthly council meetings. Dr. Whitney adored him; it was the Professor's kind, firm spirit that got him through the ordeal of starting the new venture; his inexhaustible scientific optimism that supported him in early discouragement and shared with him the responsibility of spending large sums of company money without apparent return.

"He deals," said Whitney, "in the materials of the universe. He is a creator. In his eyes the physical world around him is the expression of God; he believes that his best contribution to God's will is to study and understand nature and to use it correctly." It was a creed that the young director strove all his life to follow.

For some time Whitney kept up his teaching at M.I.T. three days a week. After the laboratory council meetings he and the Professor would go back to Boston together on the train, enjoying every minute of each other. It was another of those teacher-and-pupil relationships so productive of long-range results. They had enormous fun speculating on discoveries still to be made and so developed a little ritual on these trips which they never omitted. They would go to Albany for a dinner at Keeler's Restaurant and have Manhattan cocktails and mushroom omelet. And while the waiter hovered over them affectionately they would fly away into the future to survey unknown lands. Then they would climb on the midnight train and talk most of the night, oblivious of everything—two "absent-minded professors" such as the world delights to laugh at; two, however, who were creating a new life for the scoffers to enjoy.

Eventually Thomson gave up the Schenectady trips, saying that he was no longer needed. Whitney and his men had so much exploration mapped out that discussion was unnecessary. The Professor knew that all they needed was to be trusted and let

alone. Whitney was deeply disappointed when the association with his beloved "chief" came to an end. He never ceased to urge him to move to Schenectady, where he could have the joy of inspiring the younger men. But Thomson steadfastly refused. Instinctively he knew that his influence was more valuable the less it was actually used. Besides, he had other plans—and other obligations.

One of these, in 1902, was a grand reception given to Lord and Lady Kelvin by the American Institute of Electrical Engineers in New York. Kelvin loved America and had come back repeatedly to lecture and to receive the ovations of the New World where so many of his discoveries were being used.

Now at seventy-eight, he was the Grand Old Man of science; this visit was his triumphal farewell. He had been feted at the Eastman Kodak plant in Rochester and at Cornell, then had gone on to Yale to receive an LL.D. degree. Now he was winding up the tour in New York, bidding good-by to his American friends.

Edison, Westinghouse, Pupin, Tesla, and Elihu Thomson were on the reception committee; the dinner was given in the large ballroom of the old Waldorf-Astoria Hotel. It was a huge success, but, as frequently happened, Tom Edison stole the show. Although the speeches were intended as fulsome tributes to Kelvin, somehow every speaker found himself expanding upon Edison in the end.

The inventor sat at one end of the head table with his wife, hand cupped to ear, smiling benevolently. He was already very deaf. As each speaker sat down he grinned broadly and clapped with all his might, assuming that the remarks had been wholly in Kelvin's praise. Finally, after a particularly flowery tribute Mrs. Edison leaned over, pulled her husband's head down and shouted, "You mustn't clap so, Tom. They are talking about you!" Edison blushed crimson, sank down in his chair, and almost disappeared under the table. Whereupon Kelvin and everybody else rose and applauded and would not be silenced till the great American stood up and took a bow.

The Kelvin dinner was typical of the pleasant but onerous duties Professor Thomson was more and more being asked to perform. Always the wise philanthropist with his time, he accepted only a fraction of the demands he received; his correspondence of

this period is filled with letters begging him to take some office or lend his name to some project, and with his modest replies, explaining why he must decline. He made it a rule to accept nothing that would destroy the effectiveness of his scientific life in Lynn.

The kind of thing he enjoyed most was advisory technical effort in the public service. When Secretary Gage of the U.S. Treasury invited him to join a visiting committee to examine the work of the Bureau of Standards, he accepted at once, and served on it faithfully for many years. But when the Sunday editor of the *New York Herald* proposed to make him a regular contributor to the paper he instantly declined.

"I shrink from publicity of any kind," he wrote, "that will interfere with my work. When a man does anything of value attracting public notice all the world seems to conspire to prevent his doing more of it."

Nor would he accept the chair of engineering at Harvard University which President Eliot begged him to take. He was a member of the corporation at M.I.T. and of its executive committee, as well as a nonresident professor of electrical engineering. With these duties he did not wish for any larger share in the administrative work of education. Eliot accepted the verdict sadly. Later, in President Lowell's time, the Professor made up for his refusal by taking the chairmanship of a visiting committee and advising the university ably in the tangled matter of a joint engineering school with Massachusetts Tech.

All his life he gave unstintingly of his advice to those who asked it, especially on the subject of lightning protection, on which he was an authority. He wrote hundreds of long careful letters in his own hand. Though his secretary at the works was ready at any moment to type out these documents for him, Thomson preferred to write most of them himself at home. Night after night he would sit up till the small hours in his study, scratching away with a sharp-pointed steel pen. A fountain pen he would never use. "I intend to keep in practice," he told his wife. "Some day I may have to use a scratchy pen."

Only a few of these letters have been preserved, such as the one he wrote to his old teacher, George Stuart, in Philadelphia, scribbling at the bottom, "I have not copied this so please return it after reading." Among the missing is one that would be priceless

in the lore of the X-ray. It was in answer to a pathetic cry for advice from the pioneer, Dr. Henry Morton, who faced the first of a long series of operations on his ulcerated hands.

2

In the spring of 1900 Elihu Thomson accompanied a group of astronomers to Barnesville, Ga., to observe a total eclipse of the sun. It was the first he had ever seen and it thrilled him deeply. For the rest of his life he never missed a total eclipse if he could possibly help it and often traveled thousands of miles to see this "greatest show of the heavens," which at best could last no more than seven and a half minutes. He viewed an eclipse purely as a nature lover, never tying himself down to the technical photographic work which often prevents the professional astronomer from enjoying the magnificent sight during totality. At various times he went to Colorado, Spain, and Norway for the show and developed a special technique of his own for outwitting the clouds which so often ruined the display at the last minute. He would hire an automobile and dash through the countryside, watching the weather for a patch of clear sky, maneuvering the sun into it at the last minute. When nearly eighty he cruised through three New England states with his wife, E. W. Rice, and Rohrer, and saw the eclipse of 1932 perfectly, while many others were defeated by the clouds.

Thomson's interest in astronomy was one of the earliest and deepest of his scientific loves. But only in the matter of observation and computation did he consider it an amateur activity. In the field of optics and practical glass working he came to be considered one of the leading authorities in America.

He had learned to make small lenses in Philadelphia and had completed a successful microscope as a youth of twenty-one. Even after he had become completely immersed in dynamo building at the Central High School he took time to experiment with glass mirrors for reflecting telescopes. He found he could produce a perfectly spherical concave surface simply by rubbing two similar glass disks together with an abrasive paste between, while constantly rotating one of them to prevent unevenness. The final parabolizing could be done by a similar method. It has been thought since that an English optician named Short may have

used this scheme in 1750, but as Short had published nothing on it, young Thomson's discovery has received full credit for originality. He disclosed it in an article in the *Franklin Institute Journal* in 1878 and thus became the author of the only simple way of shaping an astronomical mirror surface. The method has been in use by professionals and many thousands of amateurs ever since.

Thomson went on and "figured" his first mirror to make the job complete but had no time to mount it in a telescope. In fact, his electrical duties were so heavy that he did little with astronomy for the next twenty years. But his interest in it was unflagging. He had always loved to watch the aurora and for some time had believed, with Professor Fitzgerald in England, that there was a connection between it and sunspots. But Fitzgerald died and "sunspottery" became the target for ridicule among scientists. Thomson, however, stuck to the Englishman's theory.

During the New Britain years a magnificent aurora appeared one night. The Professor led an expedition to a near-by hilltop and took careful notes of what was "probably the grandest exhibition I have ever seen." At the height of it the young investigators visited the telegraph office and found that many east-and-west circuits were out of service, so loaded with "stray" currents that code signals were impossible. Thomson predicted that a sunspot would be found on the solar disk opposite the earth.

Next day the group borrowed a small telescope and made an observation. There was indeed a sunspot—one of the largest they had ever seen. This and many subsequent tests convinced the Professor that there was a close connection between solar "storms" and the magnetic storms on earth that played such havoc with communication. But for years he was quite alone in the belief. His friends challenged him to explain the fact that sunspots often produced no aurora at all. His answer was simple. The spots sent out streams of ionized matter, traveling in a certain direction. If the stream missed the earth there would be no effect. It was the right explanation, but it got little encouragement then.

Later on, at Mount Wilson, Dr. George E. Hale and his associates proved beyond doubt that the sunspot is an electromagnetic vortex in the sun's outer gases and that it does indeed pour a stream of electrified particles out into space. Since then

constant work with the spectroscope and other instruments has proved that the sun is responsible for upsetting magnetic conditions on earth, just as Thomson believed it was.

In 1900 the Professor at last found time to realize his desire to build a large equatorial telescope for use on the Swampscott estate. He could have bought the instrument complete, or had it built to his own designs, for he was now well acquainted with Ambrose Swasey, John Brashear, and Alvan Clark, the leading telescope makers in America. But he preferred to do the work himself. Off and on during the years he had kept his hand in by grinding small lenses. Though this instrument was to be of major size, with a 10-inch achromatic objective, he had no hesitation in attempting it.

The lens blanks he obtained from Mantois in Paris, then worked them into shape in his laboratory over the carriage house at home, on grinding and polishing machines he built himself. Then he designed the telescope tube and mounting and had the heavy castings made outside, while he finished up the delicate driving mechanism at his own bench. The undertaking occupied him for more than a year; when the instrument was finally set up in a small observatory built for it on his own front lawn Thomson was delighted to find that he had a telescope of the highest professional grade. The objective showed a resolving power, or definition, of half a second of arc—close to the theoretical limit for a 10-inch glass.

Observation of the heavens became Professor Thomson's greatest hobby. At once he began a systematic study of the moon, planets, and stars, not merely for curiosity but to acquire knowledge. While he had neither time nor desire to become a professional astronomer, he was anxious to be so well informed that he could contribute to current discussions on the subject. At that time the 40-inch telescope at the Yerkes Observatory was the largest in the world. With the aid of this great instrument and others in America and abroad a comprehensive study of the sky had just been begun. It was a moment when fundamental hypotheses were in the making, when the theories later to be proved by systematic observation were first being proposed. This was the time when Professor Thomson's broad understanding of research and discovery could be most effective in the new science of astrophysics.

3

One of his earliest interests was in the planet Mars. At this time Percival Lowell had just opened his observatory in Flagstaff, Ariz., with its fine 24-inch telescope. Lowell was making the study of the "red planet" his lifework. Already he had advanced his theory that the "canali" or linelike markings on the planet gave proof of human habitation. He believed that Mars was dying for lack of water and that its inhabitants were supermen who had built giant irrigation works to prolong their civilization.

It was a dramatic theory and widely supported even among astronomers, for there was no other good explanation for the geometric patterns of the so-called "canals." But from the first Professor Thomson disagreed; he felt that Lowell was too credulous. There must be some natural explanation that did not require the invention of a Martian race.

His homemade telescope was large enough to give him a good view of the planet on the rare occasions when it was nearest the earth. So he set himself the task of refuting Lowell's theory. Just before the Martian opposition of 1906, the Professor refigured his telescope lenses to give the greatest possible sharpness of definition. When the moment came he was able not only to see the markings clearly but also to get corroboration from his family and friends. Several engineers made independent drawings of what they saw that closely resembled Lowell's own. They were also able to agree on the characteristic green color of the markings.

With these data the Professor worked out a theory that seemed to him logical. It was this:

Mars, though farther from the sun than the earth, receives enough heat to produce temperatures similar to our own. Though there is little water or oxygen on the planet, there may well be enough carbon dioxide to support considerable vegetation. There may even be primitive animal life. As the Martian seasons advance the warm moist climate of the equator expands toward the poles, as it does on earth, taking the vegetation with it. This produces the annual migration of living things. There being no mountains or large rivers to obstruct them, the animals can make their yearly treks in straight lines, going to high latitudes on the little globe. Repeated fertilization and the long process of wear have gradually

established paths of travel which have grown up with thick vegetation, leaving the rest of the planet a desert. At this great distance the pattern of interlacing routes can be mistaken for "canals."

When Thomson advanced his theory there were no instruments sensitive enough to measure Martian temperatures or to identify the browns and greens as vegetation. It was a pure hypothesis on his part, founded on logic. For many years afterward he and Lowell argued the matter and came to no agreement. But by the time the astronomer died in 1916 Thomson's reasoning was beginning to gain professional support. In recent years many new data have been collected with the aid of spectroscopic studies. It is now pretty well agreed that the vegetation theory is the right one. Whether there is animal life of any kind on Mars is still an unsettled question. The solution to that mystery may never come.

As Professor Thomson became more familiar with astronomical work he saw that the large telescopes of the future were certain to be reflectors with mirrors rather than refractors with lenses. The 40-inch disks of the Yerkes telescope were about the largest that could be cast of optical glass and maintained in accurate shape. Yet as the astronomers pushed farther into space they would need much greater diameters to obtain higher light-gathering power. No optical limitation was in sight for mirrors, since they could be made thick and rigid and still present smooth top surfaces for accurate reflection.

However, serious difficulties were in store if these great mirrors were to be made of ordinary glass. Expansion and contraction of the material under normal changes in day-and-night temperatures would cause severe distortion. A superglass would be needed which was nearly insensitive to temperature.

Looking about for a material with a very low coefficient of expansion in 1902, the Professor hit upon pure fused quartz as the ideal and proceeded to make experiments with it. By developing special high-temperature furnaces at his Lynn laboratory he found he could melt quartz sand and cast it into disks several inches in diameter, which did not warp noticeably even when warmed with a gas flame. There was only one serious drawback: the quartz was so viscous when melted that it could not be freed of millions of small air bubbles which would make a smooth optical surface impossible to obtain.

Dr. Hale of the Yerkes Observatory was just then beginning his researches on the sun and was having trouble with the distortion of his telescope mirrors under the sun's heat. Hearing of the Professor's experiments he wrote him in 1903, suggesting the use of fused quartz instead of glass for solar work. Thomson offered to cast mirror blanks for him at once, believing that the air-bubble difficulty could be overcome.

The following year Hale opened the Mount Wilson Observatory in California, setting up the Snow telescope for his solar research. Thomson's quartz blanks presently arrived and were ground and fitted by the Hale group. Hopes were high. But they were short-lived. The microscopic bubbles breaking the mirror surfaces caused so much dispersion of light that accurate spectroscopic work could not be done. The Mount Wilson men were forced to go back to glass.

The Professor took the setback without discouragement, confident that a technique for casting clear quartz could be found in a short time. But the problem proved more difficult than he anticipated. For twenty-five years he experimented with the elusive material before he reached a solution which was even partially satisfactory. Good quartz mirrors were finally made and used on Mount Wilson in small sizes, but to the day of his death the huge disks that he had dreamed of for astronomical instruments remained impossible to cast.

The long-drawn-out quartz problem gave Thomson an intimate contact with the professional astronomers, especially with Hale. After they had corresponded for some time Hale began to realize the Professor's rare good judgment in all scientific matters, and a lifelong bond was established between the two men. Soon Hale had formed the habit of consulting Thomson on many knotty problems in astronomy. For years a good part of the Professor's personal correspondence was with Hale and his associates.

Early in the Mount Wilson venture Hale's optician, George Ritchey, went to Lynn to discuss the quartz problem; he too formed an attachment to the Professor that continued almost to the latter's death. It was Ritchey who spent two years grinding and figuring the 60-inch reflector and five years making the mirror for the famous 100-inch Hooker telescope, still the largest in the world

in actual use. During all this time Ritchey wrote letters to the Professor almost every month, appealing to him for help and advice, discussing new ideas, once even suggesting that the American army ought to use "land battleships to crush the German western line at one blow." This was one of the earliest mentions of the modern tank.

It was to Professor Thomson that Ritchey wrote the first exciting news of the finding of "novae" or exploding stars in photographs of the spiral nebulae—a Mount Wilson discovery of prime importance in determining the size and structure of the outer universe.

Elihu Thomson gradually assumed the same position of unofficial consultant to the astronomers that he already held with the electrical engineers. A relationship to the art which had begun in an argument with Percival Lowell over the inhabitants of Mars ripened until the Professor's opinion was repeatedly sought by such pioneers as George E. Hale, E. E. Barnard, A. A. Michelson, Harlow Shapley, and W. H. Pickering.

Later, Thomson was appointed to a visiting committee for the Harvard Observatory. And in 1926 S. W. Stratton of the Bureau of Standards came to him for help in casting the 70-inch "Pyrex" disk for the Perkins Observatory.

Thomson was one of the very rare outsiders ever to gain the astronomers' full confidence in matters of general technique. This was well proved when the California Institute of Technology asked him to cast the 200-inch quartz disk for the giant Palomar telescope. That attempt failed, as will be shown later, only because the job proved too costly for the funds available.

During one of Thomson's official visits to the Harvard Observatory Sir Arthur Eddington, the great English astronomer, was the guest of honor. He and the Professor were soon deep in a discussion of cosmic physics, and presently disagreed. The point in debate was Lemaître's theory of the expanding universe, based upon the "red shift" observed in the spectra of the nebulae. Thomson did not believe that the displacement of the spectral lines necessarily meant that the nebulae were flying apart at tremendous velocities, as Eddington had deduced. A much simpler explanation should suffice, he thought. Was it not probable that the nebular light, reaching the earth through enormous reaches of

space, would suffer distortion on the way, making it quite possible that the nebulae were not moving at all?

Eddington and the others listened respectfully but were not convinced. They felt that this question was too technical for the simple solution which this "nonmathematician" had proposed. The Professor did not press the point. But he did not back down.

Several years after Thomson's death, Dr. Edwin Hubble at Mount Wilson made new observations of the nebulae which were incompatible with the doctrine of the expanding universe. Today the question is once more in argument. The red shift is no longer regarded as satisfactory proof of Lemaître's theory.

4

In the thirty-seven years of his concern with astronomy Professor Thomson wrote a great many papers on the subject, including contributions on the origin of zodiacal light, meteors, comets, the aurora, the craters on the moon, and a wealth of material on astronomical mirrors and especially on fused quartz. In his studies of the moon's surface he was again one of the earliest to arrive at a theory which has since been verified by accurate observation with modern instruments.

For many years Professor W. H. Pickering of Harvard made a special study of the moon, in both Cambridge and Jamaica. Observations of the monthly change of color of the lunar surface led him to believe that there was vegetation there. Such a theory meant that there must be an atmosphere on the moon, which was contrary to all scientific evidence. Thomson disagreed with Pickering and suggested a simpler explanation of the color change, based upon the very first original research he had done at the Central High School at eighteen. The shifting color, he pointed out, was perfectly logical in a mineral surface subjected to the violent changes in temperature known to occur between lunar day and night.

What interested Thomson much more was the origin of the lunar craters. Early observers had believed them to be volcanic; Thomson doubted this. In his view they were obviously splashes made by the impact of huge meteors at the time when the lunar surface was still plastic enough to act like sticky mud. He based his theory upon the planetesimal hypothesis advanced by Cham-

berlain and Moulton; for a long time he got little support from the professionals. But today accumulating evidence is indicating the correctness of his view.

Of all Thomson's many friends in the astronomical field his dearest was an amateur telescope maker in Philadelphia, a well-known architect named George Hewitt. The two had met by accident in an optical store as both were buying glass for lens making. The friendship ripened quickly; before long they were writing to each other regularly, swapping experiences and advice and enjoying each other as much as though they were schoolboys together.

Hewitt had been an amateur mechanic from childhood, which delighted Thomson because he could send him all sorts of complicated instructions and be sure they would be followed with skill and understanding.

"Our collaboration," the Professor remarks affectionately in his notes, "continued from the time of our meeting, about 1899, until his death in 1916. A great volume of correspondence passed between us, chiefly on telescope-lens construction. I encouraged him to enlarge his scope of operations and pass from 4-inch glasses to 6 and 9. He finally finished and mounted a 9-inch glass in an instrument which I sometimes used when visiting him. It was a good job and all right in its corrections."

When Hewitt died his widow proudly offered the telescope to a college observatory and was much hurt when the authorities demurred because it was an amateur instrument. To settle the matter it was decided to send the lens out to Pittsburgh to be tested by John A. Brashear, one of the best known experts in this country. When "Uncle John" heard that it was coming he wrote immediately refusing to do the job.

"If Elihu Thomson says it is all right it *is* all right," he said, "and there is no need of my testing it at all."

I

Chapter 23

The year 1903 was made famous in the annals of engineering by the coming of the steam turbine in the electric power field. Late in the fall a 5,000-kilowatt generator began to turn over in the new Fiske Street station of the Commonwealth Edison Company in Chicago. It was the first large dynamo in America to be operated without the help of the reciprocating steam engine.

The Curtis turbine which drove this pioneer machine was the culmination of seven years of great effort, with often discouraging results, in the shops and laboratories at Schenectady, under the direction of the brilliant engineer, W. L. R. Emmet. It represented one of Wilbur Rice's greatest contributions, for it was his courageous support of Emmet that put the development through in spite of the skepticism of the engineering world. And in a sense it was Elihu Thomson's triumph too. For it was he who had insisted, ever since the early nineties, that the steam engine must soon be replaced with a far more efficient converter of heat energy. Over and over again he had written and spoken on this theme; consistently he had encouraged Rice in the undertaking and had advised Whitney and the engineers who had struggled to produce the new materials and new super-refinements of design and workmanship which were necessary.

The steam turbine had come in the nick of time, just when the faithful old steam engine had reached the extreme limit of practical size and was about to block the whole progress of the electrical art. There would be no limits now. Hundreds of thousands of kilowatts could eventually be produced by a single powerhouse, making electricity a truly universal commodity. Under the patents of the American, Charles Curtis, and the Englishman, Sir Charles Parsons, a fresh revolution began in the revolution-filled world of electric power.

The invention of the turbine opened the modern era of giant

power networks, unifying whole nations, and in doing so gave tremendous impetus to the engineering arts. The technical men of all countries were suddenly put under pressure to consolidate their position and enlarge their outlook.

An opportunity to do this was presented in 1904 at the International Electrical Congress in St. Louis. Faithful to precedent the congress attached itself to a world's fair, this time to the Louisiana Purchase Exposition. Again the official delegates were gathered from the nations of both hemispheres and assembled in the midst of the latest display of the technical arts. And again the meeting was an outstanding success. Dr. Arthur E. Kennelly of Harvard had spent more than eighteen months making the arrangements; the galaxy of notables was more brilliant than ever.

At the opening meeting Elihu Thomson was elected permanent president of the Chamber of Official Delegates, and took charge of the congress. In his accepting address he set the pace for the new era of electric power by describing the alliance between research and the engineer, now uppermost in his mind:

> There is a difference beween the work of pure science investigation and that of the engineer. . . . It touches the matter of responsibility for results. It matters not very much whether the results reached by science are negative or positive, whether they indicate success or failure or attain expected or unexpected ends. Not so with the engineer. If he is to maintain his standing his results must be positive commercially, industrially, financially. . . . Yet it is a sign of the times that the value of research is becoming so well recognized as an aid to engineering that our large industrial organizations willingly support (it). . . . Constant additions to knowledge of nature are in themselves valuable and likely at any time to open up new channels of industry. The little streams lead to the rivers and few rivers are without commercial possibilities.
>
> The future of science and particularly of electrical science is boundless. . . . Prepare then to accept an electrical universe.

In line with this theme Thomson and Kennelly brought forth a new plan at the congress. The time had come, they felt, to unite the world's engineers and scientists in a single permanent group whose work should be continuous and not dependent upon infrequent world's fairs. The idea was unanimously approved, and

accordingly the "International Electrotechnical Commission" was created with Lord Kelvin as its first president.

Immediately after the St. Louis meeting the commission took up the task of correlating the engineering standards of two hemispheres. When Kelvin died in 1907 Professor Mascart of Paris succeeded him but himself died before reaching office. Elihu Thomson thereupon took the presidency and guided the work of international collaboration for many years. It was during his tenure that his friend Ambrose Swasey, the great Cleveland telescope manufacturer, donated half a million dollars to establish the Engineering Foundation for the furtherance of research and engineering. The foundation has become an influence of great power in the profession.

2

The year 1904 was a busy one for Professor Thomson on many fronts. Early in February the degree of LL.D. was conferred upon him by the University of Wisconsin, the first of a number of such honors to come his way. Immediately afterward he was invited to attend a banquet in New York which became one of the earliest milestones in aviation. This was the famous "Flying Machine Dinner."

A group of prominent businessmen had gathered to do honor to two of the earliest experimenters with flight. These pioneers were Professor S. P. Langley and the Brazilian youth, Santos-Dumont. Elihu Thomson was the only engineer present.

Santos-Dumont had been attracting much attention in Paris by making successful trips in a small motor-driven airship filled with hydrogen. Langley, on the other hand, had been experimenting with an "aerodrome," or heavier-than-air machine propelled by a steam engine, and was deeply discouraged. His plane could not carry a passenger; in fact it could scarcely support its own weight. Just before the dinner it had crashed near Washington. He saw little prospect of developing a steam engine and boiler light enough to permit human flight. As a sort of epitaph to his experiments he had brought along the machine itself, with his mechanic, Manly, who exhibited the strange craft in an adjoining room and explained why it had fallen.

The dinner, indeed, was given mainly as a consolation to

Langley, whom everybody respected and loved, with Santos-Dumont thrown in as an extra. It was an unfortunate mixture of guests, for the Brazilian quickly took the limelight. Few were present who did not believe that his "dirigible" would become the successful machine of the future.

Professor Thomson had not been asked to speak and so sat off to one side, becoming steadily sorrier for Langley as each address made his failure more apparent. Finally the toastmaster, seeing that the situation had come dangerously close to a funeral service, had the happy idea of asking Thomson to give his views as an engineer. He knew from experience that the Professor, whatever he said, would restore good feeling.

Thomson was entirely unprepared, having given the subject of flying no special thought. But it was necessary to say something; so he got up and began, using the scant materials at hand as the basis for a pure prophecy. "Once on my feet," he recalls, "I found I had a great deal more to contribute to the discussion than I had believed myself to possess."

He remembered having heard Kelvin pitch into the same subject in a speech two years before. The greatest living electrician had said, "The airship, on the plan of Santos-Dumont, is a delusion and a snare. Some day someone will invent a flying machine but that day is a long way off."

Taking courage from this the Professor outlined what he thought might be the future of aviation. He glanced kindly at Santos-Dumont and said that he did not see much use for the gas-bag type of flying machine, because of the danger that its hydrogen would explode and because large dirigibles would be easily wrecked in storms. On the other hand, he was satisfied that Langley had solved the problem of aerial flight from a mechanical standpoint:

> The small aerodrome of Professor Langley has made numerous trips without difficulty; surely it makes no difference whether it carried live freight or not. . . . We must not be impatient with unavoidable accidents in the pioneer work of flying. A child may have the muscles and necessary organization permitting it to walk, but it will have to learn to coordinate its muscular actions and balance the nervous impulses. In the same way the operator must learn to manipulate the flying

machine. . . . Man has accomplished so much in the past hundred years that it will not do to be pessimistic.

Professor Thomson discoursed at some length on nature's purpose in streamlining the birds and fishes and described the ideal flying machine as a kind of kite, built on the principles but not after the form of a bird's wing. At the end he predicted that the heavier-than-air machine would soon be a practical fact and that its first important use would be in war for observation and dropping bombs. He even suggested that it might be carried into battle on the decks of special ships.

When he sat down, Langley's spirits had been tremendously improved. Although it was not he but the Wrights who had got into the air at Kitty Hawk in 1903, Langley has since received credit as a leading pioneer of heavier-than-air flight. The Professor's speech and his subsequent article in the *Electrical World* on the subject had much to do with putting this credit where it belonged.

In 1909 Professor W. C. Sabine, Harvard's great acoustic expert, was asked to go to Washington to view an Army test of the latest Wright biplane. "During an interview with Orville Wright afterward," Sabine reported, "he stressed the point that he and his brother had striven only to prove by these tests that flying machines were an accomplished fact, adding that he saw no future utility for airplanes—that wealthy men might possibly take up flying as a fad. And should there ever be a war, such machines might possibly be used for scouting."

Elihu Thomson in 1904 had been nearer the truth in his prophecy than Wright himself in 1909.

It was in this impromptu way that the Professor's influence was frequently felt in these years. Some time later he was at another dinner with no invitation to speak and suddenly found himself required to give a talk. On the spur of the moment he chose the Panama Canal, which he had visited, and explained its engineering features for half an hour to a fascinated audience.

Again, prevailed upon to speak informally at an engineering affair, he made some remarks on the improbability of the transmission of electric power by radio. Months afterward he was surprised to find a verbatim copy of his talk published in the Smith-

sonian Report by the United States government. It was a fine tribute to the clarity of his expression.

3

The impulse to rise in defense of a colleague unjustly treated eventually rewarded Professor Thomson with one of the great scientific adventures of his life.

In the autumn of 1909 he and his wife visited Woodrow Wilson, then President of Princeton, to attend the annual meeting of the National Academy of Sciences at the university. One of the papers given before the meeting was a discussion of the nature and origin of Meteor Crater in Arizona. Its author was a Philadelphia lawyer and geologist, Daniel M. Barringer. At that time the U.S. Geological Survey as well as most private geologists of standing contended that the crater was an extinct volcano, and Barringer's long and passionately argued meteor theory slightly annoyed his scientific audience. As he proceeded with his speech, eyebrows were lifted all over the hall; some actually winked and smiled in full view of the speaker.

His listeners were so hostile that Barringer faltered and almost stopped in the middle. Elihu Thomson is reported to have jumped to his feet and called out, "Go ahead. Pay no attention to them. You'll prove that you are right!"

After the lecture Thomson met Barringer and with him Professor W. F. Magie, who, as head of Princeton's physics department, had given the geologist much technical help. Later, on the train to Philadelphia, Barringer looked up to find Thomson at his side; the two sat down and talked. In a few minutes they were firm friends; it was, as Mrs. Barringer later described it, a "meeting of souls." Thomson was soon associated with Barringer in the scientific investigation of Meteor Crater and eventually, with Magie, helped finance a project to develop it commercially as a mine.

From this chance meeting grew an intimate friendship with the whole family. He fell into the habit of dining with them whenever he was in Philadelphia. The Barringers had three young sons, about the same ages as Thomson's own. Soon they had learned to look forward to the Professor's visits as the high point in their lives. Evening after evening they would sit around him on the floor and listen to his explanations of natural phenomena or follow

with intense delight the magician's tricks which he loved to perform whenever children were around.

Especially the Professor talked to them of astronomy and of the observations he had made with his big telescope in Swampscott. After a time he brought a small instrument to the house, spending many evenings with the family grouped around him in the yard, showing them the double stars, the nebulae, the rings of Saturn and the moons of Jupiter, and many another wonder of the heavens. Dick Barringer was so thrilled that he built himself a telescope and later became an expert, even starting an astronomical newspaper. For years he and Professor Thomson corresponded, Dick submitting all his ideas for criticism and help.

Daniel Barringer's enthusiasm for the Meteor Crater research soon communicated itself to Thomson, who resolved to investigate on his own account. In 1911 he made a trip to Arizona and spent several days climbing up and down over the strange pile of broken rock that rises out of the flat desert in a ring nearly a mile in diameter. When he returned he was convinced that the meteor theory was the only tenable one. As was his wont with a new interest he gave a paper on it, this time before the American Academy of Arts and Sciences, predicting that the meteorite would be found buried in the ground far below the surface. In one part of the paper he explained how a large meteoric mass might have made the passage through the earth's atmosphere at a speed of some thirty miles a second, burning so little that it still had bulk enough to smash an enormous hole in the solid rock.

It was then widely held that meteors, on striking the atmosphere, vaporized almost instantaneously from the heat of friction and compression of the air. Professor Thomson maintained that this could not be so. Even though the outer layer of the body burned furiously, the time of flight was so short that the heat could not penetrate to the core. He proved the point with the analogy of a block of ice, suspended by a string and attacked by a blast of hot air.

"The ice melts rapidly," he said, "and the water formed is blown off as fast as it appears, while what remains is none the less ice to the end of the process."

The history of Meteor Crater, or "Coon Butte," as it was formerly called, begins with a legend of the Navajo Indians, who

believe that a god descended flaming from the sky and buried himself in the earth. Even today no Indian will touch the fragments of iron that are scattered for miles about this strange depression in the Arizona desert. Early American pioneers who heard the legend and explored the crater decided that it must have been made by a great comet or meteor. There was said to be more meteoric iron here than had been found in all the rest of the world combined.

However, Professor Gilbert, the grand old man of the U. S. Geological Survey, discredited the meteoric theory by showing that the compass was not disturbed in any part of the crater as it should have been if the body of a great meteorite lay buried there. His own explanation was that the crater was a "steam hole" of volcanic origin. The fact that there was neither lava nor other evidence of internal upheaval to be found within fifty miles did not disturb him. Nor did he trouble to explain why so much meteoric iron happened to be present around an extinct volcano.

In 1903 Daniel Barringer saw Coon Butte and became so interested in it that he filed mining claims there and began investigations. There was much geological evidence in support of the meteoric theory. To begin with, the rock strata around the crater's rim seemed to have been pried upward by a body forcing its way in from above rather than from below. Furthermore, the depression itself was filled with sandstone "flour," pulverized so finely that only a gigantic impact could have been responsible. Again, some three hundred million tons of great boulders had been thrown out to east and west in a regular pattern which suggested that a heavy object had struck there.

Gilbert's demonstration that the region was nonmagnetic seemed unconvincing. Barringer found the meteoric fragments on the surface to be strongly magnetized and showed that, if the main mass below was a collection of such fragments rather than a single piece, its parts would neutralize each other and produce no surface magnetism at all.

He began drilling at the bottom of the crater and worked for several years before his money ran out. There was plenty of evidence that the meteorite was there, but the large body itself could not be found. Too late the geologist realized that he had made a mistake by drilling at the crater's center. It was obvious

now that the meteorite had struck diagonally from the north and was lodged at one side. But if so, why was the formation circular rather than elliptical in shape? The paradox stumped him for a long time until one day, by accident, he fired his rifle into a sheet of heavy mud and found that no matter what the angle of the bullet was the "crater" around the hole was always round. This important discovery encouraged Barringer tremendously; from then on his one ambition was to organize a new search for the great meteorite.

4

For the first few years Professor Thomson's interest in Meteor Crater was purely scientific. But while he was busy with study and computation Barringer started work on the commercial side of the venture. An assay of the surface fragments of meteoric iron indicated more than 6 per cent pure nickel, as well as an average of $\frac{3}{10}$ ounce of platinum and iridium per ton. Calculations by several independent scientists placed the weight of the main mass at something like ten million tons. If the meteorite could be located and dug out, fabulous wealth in rare and valuable metals was to be had.

Elihu Thomson had never lent himself to the will-o'-the-wisp mining schemes which in those days impoverished so many men of moderate fortune. He did not do so now. But he gave his moral and scientific support to the undertaking and told Barringer that if and when the meteorite was found he would be glad to help with the exploitation.

In 1920 Barringer persuaded a prominent mining concern to lease a site on the south rim of the crater and sink a test hole. A churn drill was put down in the next eighteen months to a depth of 1,376 feet, where it stuck and could not be removed. The work had been very expensive, and the company abandoned the lease. But much valuable information had been gathered. At 1,200 feet the sandstone had suddenly given way to rich samples of meteoric iron. As the hole went down the proportion of magnetite had increased rapidly; the last sample had shown 75 per cent of the foreign material. Undoubtedly the main body had been located at last. It was exactly where Barringer and Thomson had decided it must be.

For five years the Philadelphia geologist was powerless to carry out his grand scheme, although as a mining venture Meteor Crater was far less of a gamble than many that had brought huge returns. But he would not give it up; indeed, as he grew older it became an obsession. He talked and thought of little else. Then at last in 1927 the boom times eased the money market so much that he decided to float a company of his own.

The "Meteor Crater Exploration and Mining Company" issued a prospectus giving a short history of the project and proposing the sale of half a million dollars' worth of stock. It stated that the meteoric mass was expected to assay at $50 a ton in "average recoverable value." As scientific backing for the project the names of Professors Thomson and Magie were given. Thomson's hand was clearly evident in the moderate wording of the document, especially in such statements as this:

> Aside from the assured scientific value of the exploration, this expenditure (the $500,000 capital) or so much thereof as may be necessary, will be purely a gamble and any subscription to the stock should be made with that fact clearly in mind. It is possible that the main body of the meteorite may be of a different composition from the fragments found near the Crater . . . or it may have been altered so as to make mining unprofitable. . . . All agree that the size and value of the meteorite cannot be known until it is actually located, measured and sampled. But there is a strong probability that ten million tons or more of unaltered material will be found.

The prospectus then stated that the average net profit per ton was expected to be $25, leaving the investor to imagine the possibilities when two hundred and fifty million dollars were divided among some twenty thousand shares of stock.

The half million was quickly subscribed. Thomson put in ten thousand himself and became a director of the company.

It is difficult to believe that the proposition could fail on the very crest of the Coolidge boom. Yet it did fail, completely. Meteor Crater remained as unassailable as when the Indians first saw it created. But it was not for lack of trying. Every penny of the capital was carefully spent, according to the most modern engineering methods.

The plan was to sink a shaft at a point on the south rim beyond

the probable position of the metal and then cut a drift tunnel northward to the meteorite's center. This was never completed, because nature's simple scheme had not been fully understood. At the 650-foot level the miners struck a water table which proved to be a subterranean lake lying over the whole region—centuries of rain caught by the crater itself. Pumps were brought into play and for a time the shaft continued to go down.

But the water was filled with sharp sand that ruined the pumps in a few days. In desperation, Barringer appealed to Thomson, who sat down and wrote an immediate reply, sketching a "centrifugal de-sander" which he devised on the spot. "I realize this may be a new invention," he cautioned the geologist. But he was sure it would work. It was an application of the old centrifugal creamer invented so long before.

The de-sander was of little avail. Drilling operations soon reached a level where the unwatering of the shaft required more power than the donkey boilers on the job could supply. The flooding problem was beyond solution by standard mining methods.

For the third time Meteor Crater had beaten its opponents.

In 1929 Daniel Barringer died and the company died with him. Thomson, now completely absorbed in making the 200-inch quartz mirror, crossed the project off as a dream that had ended. Only Moreau, one of the Barringer sons, kept up the family interest.

Though it has never been possible to finance another attempt to dig out the meteorite the Barringers have never lost faith. They believe that a successful shaft can be sunk according to the original plan if enough power can be brought into the desert to drive the unwatering machinery. Once through the water-bearing strata they are sure that a tunnel can be driven into the heart of the meteorite.

The growing threat of war after the depression revived national interest in Meteor Crater. In 1937 Hans Lundberg, a Swedish mining engineer, made a magnetic contour map of the crater region with the latest type of variometer. The results definitely located the metallic mass in a "conduit" stretching underground for a mile and a half beyond the south rim. The energy of the meteoric cluster had been great enough to drive it this distance through solid rock. The total mass was close to ten million tons, as Barringer and Thomson had predicted. More recently new calcu-

lations have yielded a much smaller figure. The question is still in doubt.

Nickel, a top-priority commodity in armament manufacture, comes almost entirely from a Canadian mine that is straining to the limit to produce enough for the allied war industries. There is so much of this metal in Meteor Crater that the government itself has become interested in its exploitation. Whether the project is revived at present or not there is no doubt that eventually the celestial treasure will be recovered. Present estimates set the total value of its burden between one and two billion dollars.

The irony of misplaced credit was added to Barringer's many disappointments before he died.

The National Geographic Magazine published an article on the crater, actually giving Professor Gilbert of the Geological Survey the credit for originating the meteor theory. Barringer saw the proofs of the article and corrected the error, thinking it was an oversight. But it was not: the article was published as written, with an inconspicuous footnote mentioning Barringer's work. Thus the man who had most bitterly fought against the meteor theory became in the public mind the one to have made its discovery.

But the world that had scoffed at Barringer in 1909 came to his aid. Vigorous protests forced the magazine to publish a full retraction of its deliberate "mistake."

Professor Thomson examines a disk of fused quartz

Chapter 24

I

With all his scientific interests Elihu Thomson still had an extraordinary amount of mental and physical energy to give to his home life. He was the complete antithesis of the absent-minded professor; his house was a perpetually exciting place for all who lived in it.

Mrs. Ramsay MacDonald, who was Lord Kelvin's grandniece, once wrote of him: "When you stay with Uncle William you begin to feel everything has a reason and that that reason may be found out; that things should not be slurred over or left to chance when you can direct them by taking a little trouble and using a little thought."

It was the same atmosphere exactly that pervaded the Thomson house. The four boys, Stuart, Roland, Malcolm, and Donald, were all born within seven years, and grew up together under their father's keen eye. They adored him because he was actively interested in them and their affairs from babyhood. He once wrote:

"If the question were, 'What ought to be the next objective in science?' my answer would be the teaching of science to the young, so that when the whole population grew up there would be a far more general background of common sense, based on a knowledge of the real meaning of the scientific method of discovering truth."

The eldest, Stuart, was a replica of his father, far ahead of his age. He was born with two teeth; almost before he could talk he showed a talent for numbers, and as a child he invented his own system of arithmetic. He would set himself problems and bring their solutions to his father for approval. Like him, he had an objective mind. It delighted Thomson to watch the boy study the world around him just as he himself had done.

But the Professor took great pains to show no favoritism. Roland was an outdoor boy, Malcolm again the engineering type,

and Donald most like his mother, quiet, retiring, and a nature lover. Each of them possessed some trait that was in the father and which he loved to bring out. His common objective for all of them was that they should observe and enjoy nature around them. To this end he played with them constantly, stepping down to their age level, always giving their projects dignity by honoring their purpose—just as his mother had done with him.

While Mrs. Thomson ran her big house with smooth efficiency the boys kept it in a turmoil of experiments with machinery, guns, and live animals. The collision between the distaff side and five energetic males, whose main purpose seemed to be to change the existing order of everything, would have wrecked a less calm person. But Mary Louise Thomson understood them all and kept the peace by stepping out of the way when necessary. She did not even object very much when one of the boys, a crack shot with a rifle, sat in his bedroom window and picked off a whole bed of tulips, one by one. Her husband took care of all such occasions, by reason rather than punishment. The great law of the household was that the destruction of life was a crime.

This he inculcated by encouraging the boys to keep pets and gardens of their own, then instructing them at great length in the fascinating habits of living things. They studied spiders' webs and fish; when they were in the mountains in the summer they scoured the woods for flowers, birds' nests and the homes of hedgehogs, raccoons, squirrels, insects, and worms. Thomson often demonstrated to them how each creature had a natural enemy and how it protected itself against destruction. Only the predatory animals would he allow them to kill, such as rats and poisonous snakes.

A fine opportunity to prove this rule occurred unexpectedly one day when Thomson discovered that the family canary was missing. He summoned the boys and told them that he knew the cat had been eying the bird for a long time; undoubtedly she had eaten it. A search was started, and finally the cat was found, with a telltale yellow feather caught on her whiskers. The Professor snatched up the animal and strangled it on the spot. It was simple retribution. He did not explain that the pussy's impulse was not criminal but only the desire for a good meal. Without knowing it, he was being more human than scientific.

On the mechanical side Thomson insisted that his sons build

things that worked. They were expected to carry their own projects through to a finish, with his advice. But he had the skilled artisan's impatience with bungling and often rolled up his sleeves and finished the job himself. Thus their lives were made exciting by a playhouse in the back yard, in which they were allowed to sleep on Fourth of July night. Roland and his father put it together board by board. When it was done Thomson cast the fireplace and chimney in concrete. When Roland outgrew it he sold it to Donald for seven dollars.

Cement work also included a sun dial and goldfish pond, made under their father's direction. The pond had an electric circulating pump and waterfall, reminiscent of the Gramme electrical exhibit that Thomson remembered so well from the Centennial of 1876. In the winter the pond froze over; it was the boys' duty to chop holes in the ice and feed the fish.

Malcolm had a passion for building automobiles, which his father approved. He was permitted to use the lathes and tools in the shop over the carriage house. He was even allowed to wreck an ancient electric carriage and take its wheels and tires.

But the most absorbing project was the real steam railroad which they all built together at the back of the estate. Thomson bought a small donkey boiler and engine castings, and they assembled them on a little flat car just big enough to carry two boys. The road was about a hundred yards long; rides on it were sold to delighted Swampscott children for a cent apiece. When the steam engine proved too weak they built a gasoline motor to take its place.

As the boys grew older their father shifted his instruction to suit their changing interests. Roland had begun to show mechanical talent. Soon he and Stuart were encouraged to start a laboratory of their own in the attic, which their father stocked with foundry and machining equipment, chemicals, and electric machines. Here he helped them make gunpowder, manufacture hydrogen for inflating soap bubbles, build batteries and telegraphs, do glass blowing, make experiments with spark coils and X-rays and countless other scientific things. He did not object, in fact, when Roland made a small electric chair and attempted to electrocute the cat. That was before the canary episode. The Professor was not in sympathy with cats.

Stuart was the studious one. Thomson spent long evenings talking over his mathematics problems, showing him that calculation was only a tool and that the fundamental concepts of science were arrived at by analytical thought. He had the great satisfaction of seeing Stuart become a scientist, a Phi Beta Kappa who graduated from Harvard with one of the few *summa cum laude* degrees ever given in chemistry.

But for all his devotion to Stuart, he loved the others just as much. Especially was he a faithful nurse when they were sick. He called them "the most irresponsible invalids that ever were" and wrote of a time when Roland fell downstairs and broke his knee but could only be kept in bed by main force, with father or mother standing guard constantly. Meanwhile, "Malcolm along with Donald manage to entertain themselves by playing at the faucets, squirting on the ceiling with a piston syringe, tearing up picture books, switching in an arc lamp in my room, demanding the joining of two (live) wires, &c."

Roland was the enterprising one physically and most often in trouble. He went to a dance one night with a high fever and was "the life of the party" in consequence. Next day he was down with pneumonia. His father abandoned all thought of work and sat by the boy's bedside day and night, holding an ice pack on his head. He did not take his clothes off for four days. When the doctor had almost despaired of saving the boy, Thomson had a bottle of oxygen sent up from the factory with a rubber tube. Whenever Roland got blue he would put the tube in his mouth and gently feed him the oxygen. It was probably the thing that pulled him through. Later Thomson did the same service for Stuart.

The use of oxygen was then almost unknown and was original so far as the Professor was concerned. At the end of his life, when he was suffering severe asthma, Roland reciprocated and fed him oxygen through a tube. The doctor wanted to put up a tent but Thomson would not have it. He said it was frightening and dangerous. Today the rubber-tube technique is in use everywhere.

Doctors learned to have great respect for Thomson's advice, even though he had no medical training. They knew that his suggestions were always based on sound reasoning. Usually his excursions into medicine were made on himself. His treatments were often extreme, but they always cured. Once he awoke in the middle of

the night with a bad toothache. As it was impossible to go to the dentist, he got a hand drill from his laboratory, bored a hole in the filling, and poured raw carbolic acid into the abscess. Next day the dentist told him that he had probably saved himself from blood poisoning.

2

Thomson's attitude about sickness was no more unusual than his vigorous behavior around the house. Though he was a polite and gracious host he detested convention of every kind; he did not hesitate to dispense with formality when he thought it undesirable. Occasionally he outraged people by refusing to do things in the accepted manner; they always forgave him in the end, for he inevitably had a good reason for what he did.

The architect of the Swampscott house was the first to suffer such a rebuff. Thomson prevented him from specifying any interior decoration at all. He said he was going to live in the house and knew what he wanted. So he planned it all himself and was satisfied. He did, however, permit the installation of burglar alarms when an acquaintance in Philadelphia was murdered by an intruder. But he disliked them heartily; they were forever going off when he opened a window. He soon had them torn out. He did not like automatic devices anywhere about the house; he never trusted them.

Toward the end of his life an oil furnace was installed to keep his rooms more comfortable. He liked to joke about it, saying he was sure it would break down. "There is nothing so reliable as a shovel," he pointed out.

The Professor afforded a curious contrast between personal decorum and mental iconoclasm that strangers often did not understand. He dressed quietly but without style. His wife bought everything for him and he wore it without a thought, just as he ate what she put before him without comment. Once when the hot-water boiler in the kitchen burst and the cook came screaming through the house for help, Thomson could not be located anywhere. His wife finally found him in the kitchen, ankle deep, bailing the water out of the back door with a pail. When the plumber arrived, Thomson stuck to him closely, advising him every minute how the repairs should be made.

As a rule he did not have much confidence in people who set themselves up as experts. A neighbor of his hired a "professional" to drill an artesian well. Thomson stood looking on for some time and then wandered off, examining the geological formation. Soon he was back. "You won't get water by drilling there," he told the man. The artisan looked at him coldly and remarked that he had been "bringing in" water all his life and guessed he knew where to find it. A week later the Professor came back; the man was still at work and had gone down several hundred feet without result. Thomson suggested a better location for the well. The driller tried to ignore him but the neighbor, who had already footed quite a bill, told him to follow the advice. The new site brought in water at once.

Now and then he overdid his independence and had to pay for it. He had the idea that letters would always stick in the mailbox at the corner unless it was well shaken; whenever he sent one of the boys out to mail a letter he would say, "Don't forget to shake the box." In the end they shook the box down and the Professor had to pay for a new one.

The Professor was very fond of art and considered himself an "expert" at it. Since early childhood he had been adept with a pencil; if he could not build a boyhood machine he contented himself with drawing it. But never did he quite learn the subtle difference between the artisan and the artist. Some of his "art work" was frankly crude. Nevertheless he kept at it and in middle life branched into the field of oils. He used to rig up a stereopticon lantern and project colored slides onto a stretched canvas, then paint in the various colors with a brush. The results pleased him; one or two he thought good enough to hang on the walls. Once he had Stuart's portrait painted by a professional. When it was finished he didn't like the mouth. So he got out his paints and retouched it himself till he had arrived at the desired likeness. He told his friends about this as ingenuously as he would have described fixing a leaky faucet. It never occurred to him that the portrait painter might consider his work inviolable. To his direct scientific mind the artist like the plumber had done a poor job that had to be corrected.

For the most part the Professor confined his artistic attempts to villainous cartoons in his letters and to penciling whiskers upon

the faces of people he found illustrated in newspapers. One Thomson drawing is a classic that deserves to be hung in a museum. It represents Donald at the age of four on the upper deck of a boat going to Toronto, being generously sick upon the head of a lady below. The lady herself is too unwell to care. The picture is so graphic that no caption is needed. Nevertheless the artist put one in.

"Donald's well-directed efforts to contribute his share to Lake Ontario," it reads.

A second masterpiece, called "The Baby Party," gives a libelous picture of the Swampscott neighbors and their offspring on a visit to the Thomson house. It is a perfect expression of a scientist's emotions when other people's children overrun his home.

Thomson's drollery bubbled up on all sorts of occasions, but it never had the slightest malice; it was no more than a sign of his irrepressibly boyish spirit. Occasionally it was real wit. When his son Malcolm got engaged to a young lady named Helen May Breed, Thomson announced the fact in a letter to his sister-in-law, Carol, and said, "Well, anyway, I hope she will!"

Everybody in the family enjoyed this sort of humor except one—a seamstress by the name of Miss Blaney, who came to the house once a week for years to fight those famous battles with the wire dress forms and the hundreds of yards of taffeta and silk. Miss Blaney always ate with the family when she was present. She was birdlike, with the bright lidless eyes of a canary. She would watch the Professor sharply throughout the meal as if she expected him to dash open her cage at any minute and tear out her feathers. But he never did. In all the years of her faithful attendance on the family the Professor never once spoke to her at the table. There was a tacit understanding between them that science and seamstressy were incurably at war. But he had a great affection for her, nevertheless.

Nothing annoyed Thomson so much as waste; he insisted on turning off lights when not in use. He saved fuel and food; above all he saved materials. His shop over the carriage house was jammed with the accumulation of a lifetime of junk collecting in the best Yankee tradition. He had the boys save all the old electric light bulbs that burned out and every so often he would go up in the attic and drop them down between the walls, "for posterity."

The bulbs, he said, had platinum wire seals and would be valuable if ever the family fell on hard times.

His passion for frugality sometimes overcame his sense of decorum. One afternoon the sales manager of the Lynn factory was taking a customer home with him in his car. As they passed a vacant lot where the company refuse was burned, they saw a well-dressed man with a fedora hat scratching through the scrap heap with a stick. The customer wondered who it could be.

"That," said the sales manager, "is our founder and chief scientist." Thomson was recovering some piece of scrap that had been thrown out of the shop by mistake.

In the early years of the century every well-to-do family owned and suffered with an expensive automobile. The Thomsons were no exception. After the steam carriage gave out the Professor purchased a gigantic Packard motorcar. He had not had it long when the rear axle collapsed. He sat down and wrote the company telling them their designs were at fault and suggesting a better construction. The Packard people replied, informing him that they had the best engineers in the country; when improvements were needed these men would invent them. Thomson wrote again, telling them who he was. The atmosphere changed instantly after that.

He never claimed to have influenced the design of rear axles, but for the rest of his life he owned nothing but Packard cars. There were no more breaks.

The Professor took his driving very seriously and obeyed every road sign to the letter. And he believed in making his own repairs. He never returned from a trip but he examined the tires with minute care; if there was so much as one tiny cut in the rubber he stripped the tire off and vulcanized it. Once in a traffic jam at a Harvard football game Robert, the chauffeur, bumped the car ahead and punched a hole in the Packard's radiator. Thomson refused to have the car towed away. Instead he sent Robert to a drugstore for plaster of Paris and had him plug the hole. By the time the game was over the radiator would hold water and the car could be driven home. The temporary repair lasted until a new radiator could be sent from the factory.

Thomson's gentle nature rarely gave way to anger. But it did once when he received a letter from the "Safety Highway League"

informing him that a certain Mary White of Brookline had complained that his tail light was illegal and dangerous and was threatening to prosecute him. In a rage Thomson wrote the woman demanding an explanation. When he found that she was a busybody who sat at her window all day taking license numbers of cars whose tail lights struck her as wrongly placed, he blew up. Before he was finished with them both Miss White and the league were very glad to terminate the matter with an apology.

3

Professor Thomson's love of nature was expressed mainly in a study and understanding of the living things about him in Swampscott. But above everything else he was drawn to the mountains. His first trip to the Adirondacks with William Greene in 1870 set the precedent; but not for fifteen years could he spare the time for another vacation like it. Then, with Rohrer, Rice, and a young colleague named Lovejoy, he began the practice of climbing a mountain each Fourth of July. Off and on for seventeen years the group assembled on this holiday and scaled some peak in the White Mountains or the Adirondacks.

The Professor was always the life of the party. For those few days he dropped every care and threw all his abundant physical energy into the adventure, hiking many miles every day, cracking jokes, playing pranks, composing earnest poetry. The party carried its own camping equipment, shot its own game, made its own beds out of pine boughs, and had a boisterous good time every minute.

One year Rohrer attempted to dynamite a huge boulder off the side of Mount Whiteface and got himself arrested by the local sheriff for destroying state landmarks. Thomson quickly appointed himself Rohrer's "attorney" and began a full-dress court action in the dining room of the lodge where they were staying. Presently it was discovered that the warrant for Rohrer's arrest had been faked by another member of the party and the sheriff persuaded to take part in the hoax. Everybody had a good laugh. On the way home in the train Thomson "immortalized" the episode in a poem of thirty stanzas which he wrote on the top of a trunk in the baggage car.

As he grew older the Professor abandoned these hilarious

excursions for a less strenuous kind of summer vacation. In 1897 he followed Rice and Lovejoy to the Adirondack League Club on Lake Honandaga. Later he built a camp on near-by Little Moose Lake and sent his family there every summer for the next twenty years. He himself appeared for long week ends. It was at Little Moose that the Thomson children got their intensive training in woodcraft, swimming, camping, and hiking, always carefully instructed by their father. Though the Professor was older now he was still an accomplished prankster. His favorite trick was to plunge into the lake and disappear, swimming under water till he was out of sight, then climbing into the bushes and hiding while the boys shrieked with fright. It never failed to get a "rise."

There was a nice group of people around the lake, among them the Mallinckrodt family from St. Louis, owners of the famous chemical works there. Edward Mallinckrodt was halfway between Thomson and his son Stuart in age and became a devoted friend and confidant of both. Edward and the Professor complemented each other emotionally; in the cruel years that came later they many times exchanged sympathy and understanding in bereavement. The young chemist was one of the many whom Thomson inspired and who in turn poured out the affection and faith that is so necessary to all who live in the lonely outposts of science.

It is not to be inferred that Elihu and Minnie Thomson had drawn apart. Theirs was the proverbially perfect marriage of the great mind and the understanding helpmeet who lives only to protect him from the small buffets of the practical world. Mrs. Thomson was not scientific by nature, nor did the Professor try to give her an artificial interest in his work. She was painfully shy—so retiring that she begged to be excused from the gatherings of celebrities which he frequented whenever it was possible. They awed and frightened her. Once when she was with him at a big scientific meeting she whispered, "Will you stand right by me, Elihu?"

In her own home she was quite the opposite—an expert manager, a charming hostess, an adored wife and mother. She loved the social and parliamentary world of church work, bridge clubs, lecture groups, and botanical societies; all her life she was a leader in these activities whenever it did not interfere with her husband's plans.

Thomson loathed social functions and never participated in them, even in his own home, if he could help it. He flatly refused to play bridge because he said it was nonsensical to entrust the game to your partner's mistakes. So whenever there was bridge in the house he would excuse himself and retire to his shop "across the bridge" in the carriage house. That bridge was a covered passageway from the second-floor hallway to the outer building. It was sacred; no one might cross it without express permission.

For the whole thirty-two years of their marriage the Thomsons were a happy and successful family unit and the delight of their many relatives. The Professor was elevated to the position of a benevolent, all-wise god. They would have spoiled him if they could; but his humble and kindly nature prevented him from being domineering or even austere. He loved them all; he was never too busy to become the moving spirit of their holiday gatherings. His own brothers and one sister were scattered wide over the United States and Canada so that he saw little of them. But he regularly sent them money and solved their problems by long, careful letters. Personal correspondence was one of the things he loved best, though he had little time for it. For years therefore he economized by writing a monthly round robin with his wife, filling it full of pranks, sketches, and drolleries like the description of a woman he had seen riding a bicycle with bloomers on. "Think of it!" he crowed. "With such a costume a woman can actually have two or more pockets that she can find, and be a real biped!"

Often he sent photographs that he had taken, pasted to the paper. One of these was a print of his first X-ray plate—a shadowgraph of his wife's hand taken in 1896.

Once a year Mrs. Thomson took the children to visit her mother in New Britain; on rare occasions Elihu went with her. When that happened the Peck household was turned inside out, for the Professor charmed his little nieces and nephews like the Pied Piper. He would shout down the chimney on Christmas and drop sooty packages into the fireplace. He would build all manner of railroads and dams and snow houses with real glass windows. He would feed quantities of candy to the children and keep them away from their meals with stories and exhibitions of the magic arts. And on special occasions he would bring out his trick doll,

which he could cause to disappear inside its clothes in full view. This was his own invention.

"Uncle 'Ihu" was an institution, for whose promised favors the youngsters would be good for months in advance.

Thomson's father never recovered from his head injury and spent his last years a serious invalid with his son Fred in Canada. But Mrs. Thomson senior was almost as much of an institution as the Professor, quite putting him in the shade when she came to visit in Swampscott each year. She had a small Mexican Pomeranian dog called "Fly," that stood only 5 inches high. It was a marvel to the boys because it would actually cry tears when it was scolded.

One of the saddest moments of Thomson's life was his mother's death in 1903. Her wonderful fighting spirit lasted till the end. When he arrived hastily from Lynn he found her on her deathbed calmly advising her youngest son Otis not to go into a certain business venture with a man she didn't trust.

With her death the old Philadelphia days were gone indeed. Daniel Thomson had died in Toronto some months before. Almost the only relic of his early home life now was the organ which he had built when a boy of seventeen in the Fitzwater Street house. He had brought its homemade pipes to Swampscott and put them, with many new and better ones, into the attic over a grille in the ceiling. The console with its automatic playing attachment he had bought from the Aeolian Company and installed at the head of the main stairs.

Elihu Thomson was devoted to his organ, and although he could play it only indifferently by hand, he got great joy and relaxation from operating the automatic rolls. Of an evening after dinner he would almost always be found at the console, rendering the classics for his own delight or for a group of friends invited in for the recital.

The organ was also a great source of pleasure to him from the scientific side. He had not only built the pipes himself but also a motor blower to furnish the air, as well as the electrically controlled valves. The boys remember him on many occasions lying in the attic on his stomach, tinkering with those valves.

The organ was no amateur affair; actually it included a number

of inventions which professional builders greatly admired. One of these was a "glass harp" which Thomson figured out and built himself. Another was a unique construction of the pipes which made them "speak" from their outer ends instead of at the base, as in the conventional organ. Thus he could aim each pipe individually to give the best acoustical results. At one time, too, being troubled with the paper rolls shifting and playing the wrong notes, the Professor devised an automatic stop to keep them in line. An Aeolian engineer who came to see him was much impressed with this and offered to buy the patent. Thomson gave it to him for nothing, asking only for the rolls of the opera "Parsifal" in return.

There was no scientific field that his interest touched in which he did not make some original contribution. After his death the organ was sold for use in a church.

I

Chapter 25

The center of the Professor's home interest lay "over the bridge" in the carriage-house laboratory. In its orderly chaos he spent many hours of every day and especially of every night. The place enthralled the boys, as Roland's description of it shows:

> As a layman you might have thought you were entering a first-class junk shop. Shelves, boxes, pegs and hooks everywhere, hung with tools, wire, metal strip, springs . . . on the right a bench the full length of the room . . . to the left a large machine lathe, further on a planer; above, pulleys and belts . . . many bins with bolts, nuts, pipe; still further on a smaller machine lathe and a bench with a complete outfit for soldering and brazing.
>
> If you turned to the left . . . a cabinet with machine tools, jigs and dies and . . . on a special bench a watchmaker's lathe.
>
> In the electrical lab . . . wires, switches, meters . . . a photographic dark room . . . cabinets containing X-ray tubes, Geissler tubes . . . a motor driven vacuum pump . . . a battery of storage cells . . . cabinets and drawers full of prisms, lenses, telescope and microscope parts . . . shelves covered with bottles of chemicals of every description.

So it went, four floors of it from the complete foundry and blacksmith's shop in the cellar to the stock piles of brass and copper and glass in the attic. Robert and the horses were confined to small quarters downstairs till the coming of the automobiles; then those rooms too succumbed to the machine age. Here Thomson spent more and more of his time as he grew richer in scientific experience. This part of his home he ruled with an iron hand; its beautiful disarray was in reality planned for greatest personal efficiency.

> Father would never let anyone clear up the laboratory because he knew exactly where to find any tool or any scrap part he might want, at a moment's notice. I think he would have

known immediately if any tool had been disturbed. This laboratory was his realm and he was its absolute monarch.

The Swampscott house was built in 1890. Gradually the home laboratory was assembled; little by little Thomson transferred his personal investigations to it, so that by the time he was seventy he did most of his work there. Much of the painstaking experiment on X-ray tubes was done in the carriage house. In the years when he was learning to manipulate fused quartz, with its melting temperature of some 3000 degrees Fahrenheit, he set up his glass-blowing outfit there at home. There, too, he built models of steam boilers, gas engines, and a new type of differential muffler for silencing engine exhausts—there he tried out his ideas for electric ship propulsion, for refrigeration, for arc lighting, and made experiments with hydraulic drive for automobiles, flexible couplings for turbines, electrical measuring instruments of a dozen kinds and applications. More and more his fertile brain worked better when he was alone, usually in the dead of night, humming or whistling under his breath, bending over lathe or instrument bench, playing all the roles of discoverer, inventor, designer, draftsman, mechanic, and office boy himself.

In working at home he had not abandoned the company; he had only shifted the scenes to make his contributions more effective. To live and work in his own way was a privilege which he demanded and was gladly given by the industry he had fathered. Save for the purely personal things like his organ and telescope and his later preoccupation with color photography, Thomson's ideas flowed wholly into standard commercial channels through the patent department of General Electric. His enormous productivity kept the department busy.

A good example of his long-range value to the company was a group of pure engineering speculations he made on electric ship propulsion. A. G. Davis, the company's patent head, asked him to consider various possible methods of applying motors to marine drive, so that pioneer patents might be taken out for future use. Thomson sat down in his study with a pencil and sketched off several schemes; in 1912 at least two were put through. Electric drive met bitter opposition from shipbuilders for the next ten years, but when boom times came the company was ready to take advantage of the more venturesome spirit. Today battleships and

large ocean liners are frequently designed for turbo-electric propulsion.

The number and importance of Thomson's patents are staggering. His first was issued to him in 1876; the application for it he wrote in longhand on the back of a student's theme. His last was granted him in 1935, when he was eighty-one. Six hundred and ninety-two patents stand in his name, the monument to a productive period of sixty years.

His average was about one patent a month for his entire adult life. Some years were better than others; in four of them he was receiving patents at the rate of one a week—fifty or so a year.

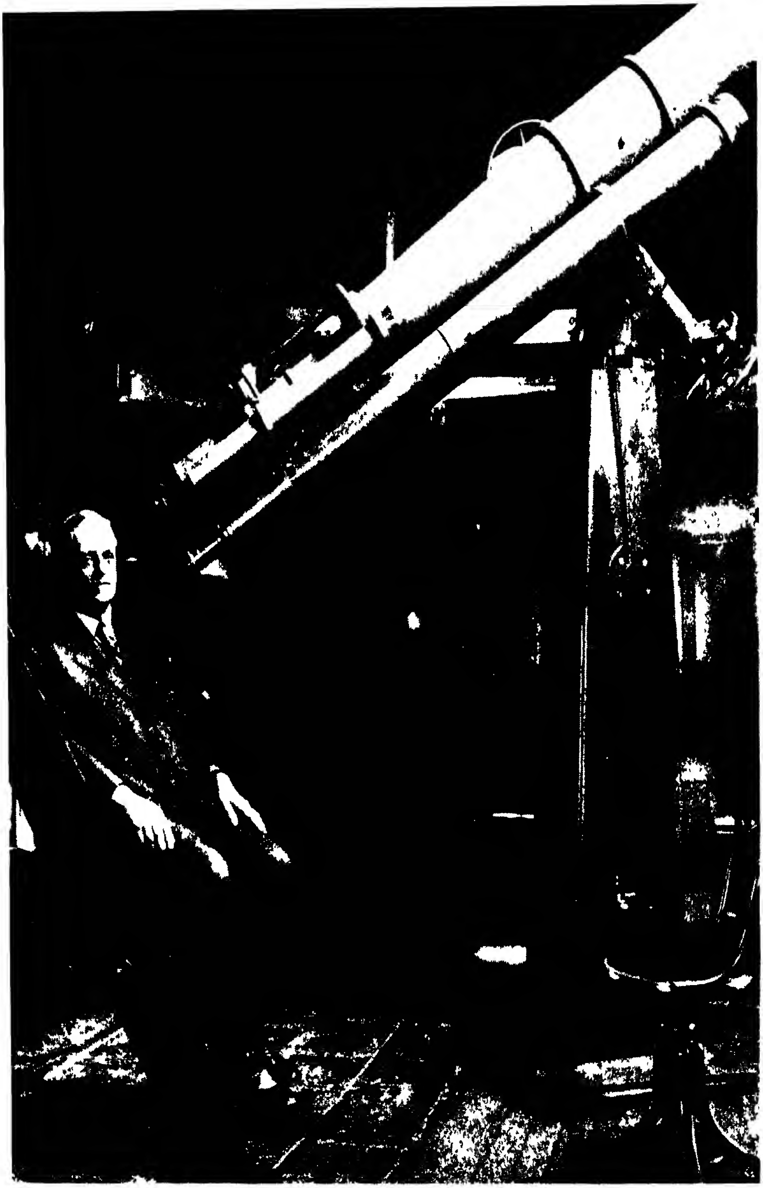
As to the importance of this avalanche (exceeded only by Edison, who had a few hundred more), Professor Thomson made at least a dozen major contributions to the art. Among them were the three-coil dynamo, electric welding, the cream separator, alternating-current distribution, the electric meter, the repulsion motor, the oil-immersed and other types of transformer, the magnetic blowout, basic inventions in trolley-car and train control, lightning arresters, and fundamental improvements in X-ray tubes and high-frequency radio apparatus.

Lumped together, the list is less imposing than the vast total of the public services to which these inventions have contributed. There is no better way to measure Thomson's influence on modern electricity than to reflect that there is not a single important application of the art to the daily lives of mankind that does not show the influence of his work.

He was not alone responsible, of course. In fact, it is certain that if he had not done all this others would have. But it is fair to say that many others would have been required to do the work the Professor did alone, in the short span of a single lifetime.

2

The inventor is often pictured by the public as a wholly romantic figure, struggling in a lonely garret or back room—a starving lunatic who suddenly "hits upon" something that catapults him to fame and fortune. That is the "Edison myth"—a pure creation of fiction. The actual route the inventor must follow is neither so barren nor so glorious, nor is it half so short and simple.



Professor Thomson with his ten-inch telescope at Swamp-scott, Mass.

More often than not the basic discovery is easily made; the real battle comes in *application*—in modifying the new idea to suit a conventional, competitive world. The toughest struggle most often comes in the Patent Office and the courts.

No man who discovers and applies natural laws today can ignore the broad consequences of his work upon the economic system. However altruistic he may be he is just as responsible for the future of his brain child as is the mother who has borne a baby. Even if he himself would prefer to leave it on the world's doorstep, he cannot. Too many besides himself will be dependent upon it for their jobs and their welfare if it succeeds. It must be protected and brought to fruition; it must be broadened and developed and promoted in the way best suited to the public good. Protection means smart legal help; development, skillful engineering; promotion, astute business handling. The safeguarding of these three steps is the end and aim of the modern patent technique.

The business of patents is a fascinating game for lawyers, a bewildering chore for judges, and a splitting headache for everyone else. No inventor likes the responsibility, but few can dodge it consistently. They may turn it over to their company experts, but that is not the end of the matter. The man who makes an invention remains its father and must always stand ready to defend it until it is finally assimilated into the body of the public domain. A wise convention has set this period of fatherhood at seventeen years, the life of a patent.

In the early days of science there was so little business competition that legal protection was unnecessary. Ben Franklin did not patent the lightning rod or the open hearth stove but gave them freely to his simple world to use. Davy made a gift of his safety lamp to the miners of England and earned the deep gratitude of the mine owners, who took on the job of applying the invention in the wisest way. Its use was so specialized that no public advantage would have been gained by a patent. Davy did not need the money the exploitation would have gained; the improvement of the miner's lot was all the reward he asked.

Faraday never took out a patent in his life, for, as Silvanus Thompson said, he "sought principles rather than processes; he searched for facts new to science rather than for merchantable

inventions." He had no need of protection, since his discoveries were contributions to basic knowledge and could not be applied except by inventions which he was not suited to make.

But in the United States of Faraday's time the situation had changed to a commercial one. American enterprise was already establishing the mechanical age. Machines as well as principles were needed to build the country; machines brought manufacture, and this involved competition. It was right that inventors should accept the possibility of great fortune as a condition of their work. Their only guarantee of reward was the patent.

Joseph Henry was the first American scientist who might properly have taken out patents. But he refused, from an exaggerated sense of duty to the art. It was a religious tenet in his family that worldly profit was wicked. The unfortunate result was that he turned his back upon practical inventions such as the telegraph and electric motor and so left them to be developed by less skillful hands. Both the people and Professor Henry thus suffered a loss.

Henry had no objection to patents for others. He simply declined, like Faraday, to concern himself with "merchantable inventions."

Michael Pupin, himself made wealthy by invention, explains this attitude of pure science clearly:

"Inventions grow old and are superseded by other inventions, and, being the creation of the constructive schemes of mortal men, are themselves mortal. But the laws which the stars and planets obey and have always obeyed in their paths through the heavens are unchangeable; they never grow old; they are a part of the eternal truth."

It was the eternal truth which alone interested Faraday and Joseph Henry. Since their day there have been many others like them—men whose talents or whose inclination have kept them out of the marketplace—Maxwell, the Curies, Pasteur, Roentgen, Einstein—innumerable explorers of the unknown who have given away freely all that they found. These are Pupin's immortals of science, whose names have been woven into the fabric of history.

Yet they would be less than immortal if the knowledge they won had not been brought to fruition by the inventors with their frankly commercial system of self-protection.

Elihu Thomson, coming upon the scene in 1870, was strongly gifted both as discoverer and engineer. But he had to make a choice—science or invention—and he took invention, at least for the moment. He had no illusions as to the world he was entering. It was fiercely competitive, predatory, even piratical—a world whose inventive pace had already been set by Edison, the great genius of practical machines.

At that time the patent system was unequal to the sudden new burden put upon it. Fantastic tangles were the order of the day; inventors spent more time overcoming each other than in outwitting nature. Edison himself suffered as much as anyone. His quadruplex telegraph was quickly bought by Jay Gould and used by him in an attempt to ruin the Western Union. Edison got thirty thousand for it and no more, though it was said to have saved fifteen millions in copper wire alone.

He once wrote bitterly:

> It is rare in this country, on account of the system of trying patent suits, for a judge really to reach the meat of the controversy, and inventors scarcely ever get a decision squarely in their favor. The fault rests, in my judgment, almost wholly with the system under which testimony to the extent of thousands of pages bearing on all conceivable subjects, many of them having no possible connection with the invention in dispute, is presented to an overworked judge. . . . Men whose inventions would have created wealth of millions have been ruined and prevented from making any money whereby they could continue their careers as creators of wealth for the general good, just because the experts befuddled the judge by their misleading statements.

Everyone, large and small, famous and obscure, suffered from this miscarriage of patent justice until, in the new century, a somewhat more realistic attitude was adopted by the courts. The patent was no longer a mere "license to fight," but a symbol of ownership which carried dignity and strength.

Even today the system is far from perfect, still subject to abuse by smart lawyers and corporations, even by governments themselves. The cartels and cross-licensing agreements uncovered during the Second World War have shown how complicated the patent situation has become. Some of the more flagrant examples

have misled the public into the belief that patents exist solely for the protection of the strong against the weak.

This is not true, as the case of Professor Sabine at Harvard will show. Sabine had worked for fifteen years to improve the acoustics of lecture and concert halls and had finally solved the problem by a combination of wall structure and felt insulation. Boston's Symphony Hall, which he designed, was the first scientifically proportioned auditorium in America and became the model for all such structures. But, though he allowed a prominent manufacturer to produce the special insulation required, he refused to patent his invention.

In the midst of remodeling the assembly hall of the Metropolitan Museum in New York, Sabine, the museum, and the manufacturer were suddenly halted by an injunction. One of Sabine's former students had stolen the idea and applied for a patent on it. The professor did not want to fight, but on the day before the patent was to be granted and published by the government his friends rose angrily in his defense. Colonel Henry Higginson wrote to Elihu Root and Senator Lodge; President Eliot sent a telegram to President Taft. Frederick P. Fish started proceedings against the Patent Commissioner in Washington.

Government printing presses had already started rolling off the new issue of the *Patent Office Gazette*, with the patent recorded in it. The commissioner pointed out that nothing could be done to stop it. But Taft called him to the White House in person; the presses were stopped; many thousand copies of the *Gazette* were recalled and the notation "Withdrawn" rubber-stamped across the offending patent notice.

After this Sabine, strongly taken to task for his neglect, took out the patent himself at once. It was not only the injustice that had brought the President into the affair, but the certainty that only Sabine could properly develop and apply the acoustic idea for the public good. This is the only case on record in which the President of the United States interfered in a patent fight.

3

Elihu Thomson's career was fairly free of such mistakes, but the patent nuisance hung over him constantly. In the celebrated case of the alternating-current system patent, held up by litiga-

tion for seventeen years, he was the loser. He had made the original invention in 1878 but for reasons of public safety had not applied for the patent till 1885. "Interferences of extraordinary length and complexity," says A. G. Davis, "intervened, and the patent did not issue till 1902. When it did issue it covered every alternating-current distribution system in the country and purported to grant, for seventeen years from 1902, a monopoly on such distribution. It is not surprising that under these circumstances the courts held the patent invalid."

All through his middle life, Thomson had to drop work and go into court repeatedly to testify as an expert in patent litigations. His testimony was so simple and so positive that the company lawyers always tried to get him on the stand, while their opponents tried equally to keep him off.

The reason was that the Professor's honesty could never be held in doubt. He told the truth, no matter who was the loser by it. The famous Berliner microphone case well illustrates the point. Frederick Fish, having become the attorney for the Bell Telephone interests, once had to defend the Berliner patent against Western Union, who sought to show the priority of Edison's microphone, which they owned. Fish begged Professor Thomson to come to New York to testify in Berliner's behalf. Thomson studied the court records carefully and then refused. "I can't do it," he wrote Fish. "It is my honest opinion that if anybody invented the carbon microphone transmitter it was not Berliner but Edison." This was a hard blow to Fish, but, having been in the electrical business all his life himself, he went into court and won the case alone.

More useful was Professor Thomson in the Sundh electromagnet litigation, which his testimony won for the company. But in the contest which raged around Dr. Coolidge's ductile tungsten for lamp filaments, he was the mainstay for years. The moment the product was marketed rivals dragged it into court, where it remained for nearly the entire life of the patent, and emerged shorn of half its protective value. What had sustained it so long was chiefly Thomson's brilliant dissertation under oath on the history of the incandescent lamp. Because of it the company won the case in the lower court. When the higher court affirmed the decision, Davis wired Thomson these congratulations:

COURT OF APPEALS AFFIRMS LOWER COURT IN TUNGSTEN CASE. THINK LARGELY DUE TO YOUR EFFECTIVE DEPOSITION.

The telegraph company, however, modified the praise, so that the last line Thomson received was this:

THINK LARGELY DUE TO YOUR DEFECTIVE DISPOSITION.

The Professor only laughed. It was no more unexplainable than the rest of the patent nonsense.

Although the worker in pure science is usually free of these patent burdens, he has quite as difficult a time defending himself in the abstract world in which he lives. If deliberate pirates are few, confusion and duplication are always present to rob a man of the credit upon which his reputation depends.

Faraday, scorning patents, still had to deal with the practical world. In 1832 he made the mistake of sending a short résumé of his discoveries in electromagnetic induction to a friend in Paris. The friend instantly published them, without permission, in Faraday's name. Two Italian scientists, supposing the discovery public property, repeated the experiments and published their own account of them, accusing Faraday of plagiarism and making scientific errors. The Englishman was furious but could do nothing about it. Thereafter he established the practice, soon universal, of dating a discovery from the day of its first communication to a learned society.

It was this principle that Roentgen used to guarantee the X-ray to the whole world.

Sir William Crookes summed up the matter in three words:

"Work, finish, publish."

It is a formula which, if faithfully followed, will avoid all arguments and place the credit where it belongs.

But no scientist is careful enough to avoid all mistakes. Thomson himself repeated Faraday's original error in 1919. In that year he heard that large deposits of helium had been found in Texas. Immediately his old high-school experiments with nitrous oxide came back to him. Why could not this inert gas be used with oxygen as a special breathing mixture for divers and sand hogs, to avoid the bends caused by the nitrogen in ordinary air?

He wrote to Dr. Whitney in Schenectady, proposing the scheme, and also to Professor McLennan of the University of Toronto, who had invited suggestions for helium applications. Then he asked the Bureau of Mines to send him some helium for experiment. The bureau ignored his request. McLennan did not reply but without permission sent the suggestion on to the British magazine *Nature*.

Five years later the bureau published an account of successful experiments with helium in caisson work, claiming complete originality. Professor Thomson again wrote the government scientists, reminding them that the suggestion was his own. Again they ignored him. When the news came out in 1927 that U. S. Submarine S-51 had been raised from the bottom of Block Island Sound with the help of the helium mixture, the Professor sent the whole correspondence to *Science*.

"The moral to be drawn from all this," the Professor observed, "is: If you have a good idea, publish it at once, or patent it, or both, in which case it is not so easy for the other fellow coming along years later to adopt it without giving credit where credit is due."

There is no doubt that the helium idea was original with Professor Thomson. But in spite of the fact that the gas is universally used today by our Navy in the "helium hat" and the Momsen lung, he has received no part of the acclaim which belongs to him.

The loss of the helium credit was unfortunate, but it was dwarfed by an opportunity that Hermann Lemp and the Professor had missed in 1893—an opportunity that would have made them pioneers in the photographic field.

It was a favorite trick of Lemp's to carry many unsolved problems in his head, letting them lie undisturbed in his subconscious mind. Often an obstacle that had stalled him for months would suddenly be hurdled by this mysterious faculty, the solution bursting upon him out of a clear sky. While he was listening to the speeches at the dinner of the Electrical Congress in 1893, a basic improvement on the photographic plate suddenly occurred to him. He had long been puzzling over the matter because the Professor was so bothered with the heavy, breakable glass negatives of the day. Why, thought Lemp, should we not use celluloid

instead of glass to support the photographic emulsion? It is light, transparent, and can be rolled up.

After the show he hurried to Thomson with the idea. The Professor thought the scheme worth a try. But back in Lynn both of them were immediately occupied with other things and they forgot all about it. Within a year George Eastman was struck by the same idea. He did not ignore it but founded on it the great industry that bears his name.

4

Fred Fish once praised Professor Pupin for the remarkable success of his loading coil for telephone cables. He asserted that it had saved the telephone company a hundred million dollars in twenty years. "If you want to buy the invention back," he added, "we'll sell it for that and throw the company in with it. We wouldn't be worth a nickel without the loading coil."

"Who got the hundred million?" Pupin asked. "I didn't."

"Neither did we," Fish assured him. "The public got it."

That is the way with all great inventions. The incandescent lamp, the electric motor, the telephone, the vacuum tube—all have made fortunes for their originators, fortunes that become insignificant in comparison to the advance in national wealth. The real beneficiary of a great invention is bound to be the public itself.

Elihu Thomson was comfortably well off but never a wealthy man, as fortunes in America go. He was not interested in making money; his salary, even in the gaudiest of boom times, was not a tenth part of that paid the average movie star. This was not because he lacked business acumen but simply because he did not want to be bothered with a large fortune. He could have had it if he had wanted it; his pupil, Wilbur Rice, made millions.

Yet, with what money he did have he lived wisely and used his small fortune in many a worthy cause. To the end of his days he was Scotch and hated to see money wasted. Once when he had given twenty-five thousand dollars to a scientific society he discovered that somebody else had given four million. He was disgusted. "I might just as well have saved my share," he said.

Most of his philanthropies were connected with science or education or with his own family. He was always ready to con-

tribute to the support of his brothers and sisters when they needed it, though he kept a close watch on the genuineness of that need. His sister Adelina had married a brilliant but rather scatter-brained engineer who once worked for General Electric and was later the mayor of an upstate New York city. Thomson sent her a regular check and finally bought the mortgage on her house and gave it to her. But not until she had promised to sell the superfluous furniture and pictures and "make Herman give up the deals and schemes which a mild snowstorm can upset."

The Thomson family accepted their brother's help gratefully but did not victimize him. They were too Scotch to be good spongers. The youngest, Otis, was once offered a job at Schenectady and went there to interview Rice about it. Otis had a combination of Elihu's able hands and artistic flair; he was a top-notch engraver in his own right. But when Rice offered him more than he was worth he demurred. Why so much money? he asked.

"A little extra for the sake of the blood," Rice said, unwisely.

"Then I won't take the job," Otis retorted. "I'm used to *earning* my salary." He went back to Philadelphia without further word.

Thomson was a man who would never let his friends down when they needed help, but he was thoroughly impatient with strangers who came to dun him or wrote him begging letters. Unlike most prominent men he often answered such people, blasting them for their unworthy conduct. Sometimes he would go downstairs and face a salesman and turn him out of the house himself. It gave him real satisfaction.

As for investments, the Professor was conservative to a fault, sticking to long-term securities in industries which he knew must succeed. Rice occasionally advised him but always insisted that he didn't need any help.

Back in the early days of the telephone the Professor had bought $3,500 worth of stock in the Gray Telephone Pay Station Company. He did this because he believed in the future of the invention. His associates thought he was foolish but they lived to see him receive 100 per cent return on his investment every year. His judgment of the value of the Calumet and Hecla mines was the same. He knew that copper would some day become a basic commodity, so he bought a little stock. It "paid off."

Only once did he slip in his estimate of a financial risk. This was when he was persuaded, with various Philadelphia friends, to back a mining property in Alaska. The venture paid dividends from the beginning—what his friend John Hays Hammond called "Irish dividends," out of the pockets of the stockholders. It cost the Professor a good many thousand dollars before he was through.

The only financial relationship which Thomson bitterly resented and eventually repudiated was the patent arrangement with Houston. After he left Philadelphia the Professor tried to sever all ties with the man who had caused him so much trouble. But Houston hung on resolutely and for years bothered him with letters about investments and about company business which no longer concerned him. Later on he fell to writing scientific fiction for boys. Every book he published he sent to the Professor, telling him that such and such a character was meant to be Thomson himself. The Professor would read them, furiously scratch out whole paragraphs, or annotate them with the word "No!" and send them back.

At one time Houston received a large bequest but soon lost it all in worthless mineral lands in Kentucky. After the money was gone he fell back on his friends—a philanthropy in which Thomson declined to join. In the end Houston died a pauper. Some months later Carl Hering, a prominent colleague of Thomson's, wrote him that he was soliciting contributions from ten of Houston's old associates to support his two sisters. The Professor's reply, which is lost, must have been frank, for Hering wrote again, apologizing for his request, saying that he "had no idea of the real situation."

In the end Thomson contributed his share and thankfully buried the whole matter forever.

Chapter 26

I

During 1911 the Professor took his wife and the two younger boys to Europe on a typical American junket, going to France, Spain, Italy, and Germany. As the President of the Electrotechnical Commission he presided at the annual meeting in Turin, Italy, where he made a great hit among the foreign engineers and scientists.

On his way back he stopped in Germany for a few days, the guest of the A. E. G. engineers, and was treated with the greatest respect and consideration. When he returned to Lynn, he found that Hermann Lemp had been in Europe at the same time, studying the Diesel engine. They talked over the experiences and swapped impressions with delight. After a time Thomson said, "We are going to have a big war in about three years."

"What makes you think that?" Lemp asked.

"In Germany," said the Professor, "I was shown many things, as a matter of courtesy; many things which I should probably not have been shown. I was taken to one of their large storehouses where they kept their small-arms ammunition. There were tremendous quantities of it."

"The smokeless powder in those cartridges," observed Lemp, "it is rather perishable. It begins to weaken after two or three years."

"Yes," said Thomson, "that is what I am thinking. They plan to use it within that time."

Professor Thomson's forecast of a planned German attack in Europe was not without confirmation. He wrote later:

> In 1912 our head official was in Europe (in Germany) and on returning home remarked to me, "I saw in one works a huge building five stories high packed from cellar to roof with torpedoes for sea." These were the kind used in submarine attack. Extensive submarine use was evidently planned ahead and full provision therefor existed in 1912.

> Also and quite significant in 1912—a well-known chemist coming back from Germany asked me if I could guess what use could be contemplated for great stores of liquid chlorine in steel tanks. He had seen great piles of these in his visit to the chemical works in Germany. I couldn't guess any use; but the first gas attacks (made with chlorine) told the story. And yet with all this some people affect to have doubts as to who made the war.

Nevertheless, the years leading up to the holocaust were as free of apprehension for Thomson as for the rest of the world. They were golden ones for him. In 1910 he received the Edison medal from the American Institute of Electrical Engineers—the first award of this honor to be made. In connection with this he visited the Edisons at Orange and spent an amusing time with them, chuckling over the competitions of the old days, solidifying a friendship which had always been neglected before.

Edison loved to tell stories on himself to illustrate the depth of his concentration, such as of the time when he went to the Newark City Hall to pay his taxes on the very last day of grace, stood in line for an hour and then, reaching the window at last, forgot his name and was thrown out.

"What did you do?" Thomson asked.

"Do? I went back later and paid up—with a twelve-and-a-half per cent forfeit for being late."

The Professor said that absent-mindedness had never been one of his personal charms; he always seemed to know where he was and what he was doing.

"I envy you," Edison grinned and told him the famous story of the cigars. He used to hate administrative work in the early days and went to his office at 65 Fifth Avenue as rarely as possible. A box of expensive Havanas that he kept in his desk there was always empty—pillaged regularly by his assistants. Finally he got a friend in the cigar business to make up a boxful of fakes out of cabbage leaves and brown paper. After a trip to the west he found that these were gone too.

"You must have had a Steinmetz in that office," put in Thomson.

"Oh, no," said Edison. "My secretary had packed those

cigars in my baggage when I went to the coast. It seems I smoked them all myself."

Honors and duties had been increasing for the Professor steadily. In 1909 he had received the degree of Doctor of Science from Harvard, had become a member of the Rumford medal committee and of the group which made the Edison medal awards. He was busy with Meteor Crater and with a delightful correspondence with John Brashear, the telescope maker of Pittsburgh. President Maclaurin of M.I.T. was consulting him about the best site for the new buildings, made possible by the magnificent gift of a certain "Mr. Smith." Harris J. Ryan, Gano Dunn, Ambrose Swasey, and many another prominent engineers were writing him in praise of his articles and lectures. And besides all this the Professor was making frequent trips to the Mount Wilson observatory to consult with Hale and Ritchey, and was serving as an officer of the American Philosophical Society, the International Electrotechnical Commission and many another organization besides. His life was brimming over.

For years his one-time protégé, Dr. Whitney, had been trying to get him to join the laboratory staff at Schenectady—with no success.

"Is there anything that I can do or say," he wrote in 1912, "which would induce you to live in Schenectady and have a share in the fun? . . . Boston and Lynn are still pretty near to us, and New York and Washington are not far away. The Adirondacks are at the back door and the east wind never gets up here. Please let me keep at you if there is a scintillation of a peradventure of possibility about it."

If any man on earth could have lured Thomson to Schenectady Whitney was the man; his letters were great sales talks, for he passionately meant what he said. But the Professor answered always in the negative. He was too old a man now to make the change. And he was too happy where he was.

2

Yet, in the back of his mind there was deep foreboding. He knew that terrible forces were at work in the shadows of Europe.

It was no surprise to him when the explosion came in August, 1914. He had been corresponding regularly with Silvanus Thomp-

son, noting the increasing strain in the aging Englishman's mind as the war clouds gathered. A few months after hostilities began Silvanus wrote him graphically of the scientist's struggle to be impartial yet loyal:

> These be dark days; happy are you who do not have to be reminded every day and hour of the horrible shadow of war. The European Armageddon is truly a terrible affair. It takes much out of one to have to insist again and again that there is another side to the question of patriotism: that there are Goths as well as Huns: that revenge for the sake of revenge is a crime that recoils on the would-be avenger. . . . The simple truth is that war at its best is devil's work: and when the evil passions are let loose the vilest deeds are done. The modern blackmailing of whole undefended populations, with wholesale slaughter when blackmailing is resisted, is a feature of this war without parallel in our time.
>
> I trust you are well and that you find time to pursue scientific work. It is difficult enough at the best of times to keep alive the torch of research; and now trebly difficult.

Professor Thomson took a less lenient view toward the German war machine. From the first day he hated the Kaiser and his clique virulently, then gradually extended his resentment to the whole German nation. To Thomson's mind war was something more than a crime against humanity—it was a crime against nature and God. More damnable than the killing of men and women was the strangling of their efforts to improve themselves. It was the waste of time and talent rather than the spilled blood that enraged him.

The coming of war abroad seemed to be the signal for serious trouble at home. Mrs. Thomson was far from well. In 1914 she had a serious operation which left her a partial invalid. For the Professor it was a most disturbing experience; he was not satisfied that the doctors knew what they were about. He felt that the surgeon had "taken out too much," that the operation had been an easy way out medically, but not necessary. He resented deeply the nonchalant way in which the doctor lost interest in his patient the moment she left the hospital.

In the summer of 1915 there was a brief return to health when the Professor and his wife traveled to San Francisco to see the

World's Fair. She was like herself again in her seeming terror of public notice, and especially when she gazed at the great Tower of Light that her husband had suggested and company engineers had installed and said,

"Elihu, they should have given you credit for it. You did it!"

But he said, tenderly, "There is glory enough for all in this world, Minnie. Let it go."

Back in Swampscott she was ill again, without apparent cause. This time it was a cough that hung on and would not yield to treatment. It was not very bad; she insisted on having only the family doctor and then did not call him frequently because he was so old. So the heart disease from which she was suffering entrenched itself for lack of proper diagnosis.

Elihu Thomson's black year of 1916 started blackly. His wife was worrying about her heart but saying nothing, getting steadily weaker, while the doctor treated her for a cough. Then in March she collapsed. The Professor rushed a Boston specialist to her side but it was too late.

He was helpless when she whispered one day:

"Elihu, try and save me. I want to live. I have such a happy life!"

She died on the nineteenth of March, ten days before his sixty-third birthday.

Elihu's grief was terrible in its restraint and bitterness. Over and over he repeated that Minnie's death had been unnecessary and reproached himself for failing to provide expert help in time. His sons gathered around him and tried to lighten the burden. Then, just as he was getting his feet under him, word came that George Hewitt had died in Philadelphia.

"My cup was full when mother passed away," he wrote to Roland, "and now there is this added blow. . . . I may, on learning from Mrs. Hewitt the time of the funeral, take train so as to pay a last tribute to one of the dearest, if not the very dearest, of all my friends."

All at once he dreaded travel, with all its reminders of happier days. But he went and bore the added pain of his friends' sympathy. Hardly was he back in Lynn but he received a letter from Mrs. Thompson in England. Silvanus had died "before his time, from strains due to war."

But there was still one loss to come; in November his old friend Percival Lowell passed away, bringing to a close the long amicable argument over the canals of Mars.

Elihu Thomson suddenly realized that his old life was over. At sixty-three a final barren period had begun.

There was, indeed, a change, but not all on the gloomy side. That fall Stuart married, then Roland, and then Malcolm. Their father, says Roland, "approved most heartily. His interest and his devotion to us increased rather than diminished." Malcolm and Donald continued to live on the Swampscott estate. The new young wife added her affectionate care to theirs. Stuart and Roland had gone to Schenectady to work for the company. Stuart was already making a name for himself in Dr. Whitney's laboratory. He had become just what his father hoped—a chip off the old block.

By December Professor Thomson had regained his spirits enough to go to New York to receive the John Fritz medal of the combined engineering societies, which was presented to him by President Maclaurin of M.I.T. Next day *The New York Times* published a long editorial on him which began thus:

> A Great American
>
> To how many hundreds of thousands of Americans is the name of Elihu Thomson even known, or if known, does it connote anything more than some vague notion of science or invention? In a popular referendum where, say, the twelve most "famous" or "greatest" men in the country were to be selected, how many hundreds of thousands, how many thousands of ballots would he receive? The quiet, fruitful labors of men of science pass unnoticed by the general in every nation. Elihu Thomson, English by birth, is an American citizen of whom the United States will boast hereafter. He is of the minds, few in every generation, that produce a great and lasting effect upon national welfare and industrial progress, that fructify civilization by the originality of their thought and their scientific achievement.

The Professor had attained his desire; he was unmolested by the public yet celebrated as a leader in his profession. In a vote of a group of leading engineering professors, naming the top men in

international science, published by the *Electrical World*, he stood in fourth place, sharing equal honors with Hertz and Henry. The three men ahead of him were Faraday, Kelvin, and Maxwell.

As if to signalize this honorable position, he received the Hughes medal from the Royal Society in London. Then shortly, he was made a member of the National Research Council, under the directorship of George Hale. The council's one aim was to mobilize science for the world conflict which only the politicians still believed could be avoided.

Elihu Thomson's official contact with the war had begun.

3

As war moved westward across the Atlantic there was abundant work to keep Professor Thomson from dwelling on his bereavements. In February, 1917, he received, in addition to his duties on the National Research Council, an invitation to assist the Naval Consulting Board in working out measures to defeat the U-boat. Soon he was plunging into a whirl of conferences and committee meetings in Washington and New York, where he was associated with R. A. Millikan, General J. J. Carty, A. A. Michelson, and other prominent physicists and engineers. The finest minds in the United States were joining together to solve the submarine problem.

In this work the Professor renewed contact with another old friend, Reginald Fessenden of the Submarine Signal Company, whom he had advised in the first transatlantic radio trials in 1906. Fessenden was conducting experiments which eventually contributed to the famous "Asdic" submarine detector of the Second World War. Meanwhile, war research went on day and night in the laboratories in Lynn and Schenectady, one outstanding result being the "C-tube" detector which provided Allied warships with a sharp ear for submarines and contributed heavily to their final downfall.

Another valuable war contribution made by the Professor and his staff was fundamental development work in high-grade optical glass for use in range finders, gun sights, and binoculars. The United States had foolishly imported all its optical glass from Germany up to the very moment of war. The cutting off of the supply created a serious bottleneck, which the Thomson Labora-

tory, the Bureau of Standards, and the glassmakers solved among them.

Still other war research included fire-control equipment for naval guns, the production of cheap nitrates for explosives, and the welding of steel ships to replace riveting. The Professor was in his element.

With all this work on his no longer youthful shoulders Thomson still had time to worry considerably about his four boys, all of them squarely within the draft age. "Since the conscription law has passed," he wrote Roland, "I have been exercised about you boys for you are all I have now." His fears were soon realized, for Donald went off to join the Navy at the first possible moment and, when a tedious period of camp life confronted him, insisted that his father and brothers use their influence to get him transferred to the Army so that he could see action in France.

Stuart, meanwhile, had gone to Washington for a dollar a year as a consulting chemist for the Bureau of Mines. Malcolm was there already, working on airplane engines at the Bureau of Standards. Only Roland was left behind, much to his disgust, having been deferred from military duty at the request of the General Electric Company.

Professor Thomson had reason to be proud of his four boys and the able help they were giving their country. He did his best to put worry behind him and to plunge into war work on his own account.

Stuart made a name for himself immediately. He was brimming with ideas, one of which he worked out with Rice's son Chester. This was a novel form of compartmentation for cargo vessels to resist torpedoes. He wrote his father about it and received his warm praise. A successful model was built and tested.

But so far as the records show the scheme was never used. That was not unique. Edison, working in camouflage, wrote Fessenden angrily that "everything I have done has been turned down and I think this is true of all others." Even science was unable to clear away the conservatism and red tape of war; many an original suggestion languished on the desks of the military.

The authorities were not wholly wrong in this attitude; science as well as the "brass hats" was making mistakes. Karl T. Compton, then a professor of physics at Princeton, was involved in a

good example of it. He had been summoned to Edison's laboratory to help improve the alcohol fuel used in torpedoes.

> In about three weeks I reported to him that I had found three fuels which seemed to offer possibilities. Mr. Edison disposed of these solutions in three sentences: "Fuel A can only be obtained in Germany. Fuel B has been tried but discarded because of the danger of explosion. Fuel C, which includes wood alcohol, is no good because the sailors drink the damn stuff."
>
> So I went back for another couple of weeks and returned with a fourth solution. Mr. Edison took the papers, looked over the calculations, muttering the while to himself, and then said: "When I don't understand work like this I get two men to work at it independently. If they agree, maybe it is all right; if they don't agree, I get a third man. Go up into room—— and see whether you agree with a young fellow from Columbia University whom I put to work on the same problem."
>
> On interviewing this Columbia scientist I found that we agreed entirely as to method but disagreed radically as to conclusions. Whereas I had found very few fuels possibly superior to those which the Navy was using, he had found that almost every fuel was superior. On looking over his work, however, I found that he had based all calculations on a formula for alcohol, $C_{12}H_{22}O_{11}$, which is sugar. In other words, he had been actually finding out what fuels would be better than sugar for driving the Navy's torpedoes. When I asked him where in the world he had got that formula for alcohol he said, "You see, I am a mathematician and not a chemist, so I went to the library."

Professor Compton turned his own calculations over to the Navy, with what results he never found out.

Stuart Thomson, however, did not fall prey to the general confusion. Soon he received a captaincy in the Army and was given a job at the proving grounds outside Washington and put in charge of redesigning the bombs which the Air Corps was dropping on the Germans. For accurate markmanship exact aerodynamic calculations were as necessary for bombs as for projectiles.

The work was intensely interesting but a fearful strain. Stuart spent most of his time in a small concrete dugout close to the experimental target, watching the descent of test bombs through binoculars. The aim of the aviators was poor; the young scientist

would have been safer on the battlefront in France. He left the job at the end of the war a complete physical wreck.

His father's intense joy at his return in the winter of 1918 was short-lived. In February Stuart was confined to his house with a cold. A tooth abscessed and he went to the dentist and had it out. The strain of the operation was too much. In a few days he was down with the deadly "flu," and died in March, that fateful month which had brought Professor Thomson so much joy and sorrow all his life.

Almost at the same time came the death of another great scientist and colleague, Professor Sabine of Harvard. He had been in France for a year, working to improve sound detectors for the Army and the Submarine Service. Constantly under fire, this gentle and retiring man had refused to give the time to an operation which he desperately needed. Immediately he returned home he was laid low by influenza.

Stuart Thomson and Wallace Sabine were only two of the many scientists who gave their lives unsung behind the lines of the First World War. Their one compensation was that they did not know they had died in vain for the cause of freedom.

Professor Thomson was dazed by this new tragedy. But there was still one more to come. On the heels of his son's death he received a letter from the Federal Income Tax Division in Boston, demanding to know why his son Donald had failed to file a return. The officials had not yet learned that the young man was abroad.

In a longhand script that was for the first time becoming shaky, the Professor wrote the collector a pathetic letter. Donald was somewhere in France, he did not know where. He had written him repeatedly, but the letters had been returned unclaimed. He did not even know whether his son was still alive.

A little while later Donald returned. He was going deaf from causes unknown. To Thomson this was the war's final blow.

Yet his spirit was not killed. He saw clearly where the awful responsibility for the conflict lay. In an address before the Franklin Institute he said:

> We have among us many who have blamed scientific developments for much of the terrible war we have so recently passed through, forgetting that a simple, short bar of that most useful of all metals, steel, can by the simple act of sharpening

one end thereof, be converted into a very dangerous weapon; but without the hand and mental resolve to wield it, how harmless! We will eliminate war, that horrible spectre which menaces civilization, when we, through understanding, unite the souls of men in the conquest of nature by science; when we obliterate greed, dishonor and bitterness from men's minds; and when we substitute for these evils candor and generous regard, with a passion for the real truth of things in our relations in life.

For his part he was ready to go on, proving what nature could do when used as an ally and not as an evil witch.

A somber note of satisfaction came to him soon with a communication from the War Department. General Billy Mitchell had just proved by test that aerial bombardment could sink a battleship in a few minutes and had predicted that the nation which possessed the strongest air force could never be successfully challenged.

The War Department wanted Elihu Thomson to know that General Mitchell had used Stuart's bombs.

Chapter 27

I

During the war years Elihu Thomson had been taking a quiet but important part in a matter that was of great interest to American education. This was the establishment of a joint engineering school by Harvard and M.I.T. The project failed, but not because he did not exert his utmost influence to bring it about.

In 1903 Gordon McKay, a manufacturer, died and left a large fortune to Harvard University, the income from which was to be used to finance a graduate school of applied science, after certain life interests expired. The bequest revived a long-standing plan for uniting the scientific teaching of the two institutions. There was much opposition from both faculty groups though Thomson, President Eliot, and many others favored the scheme. The matter moved along very slowly until 1915, when a final agreement was reached. Lowell and Maclaurin, the new presidents, were enthusiastic for the union.

It was then decided necessary to test the legality of using the McKay money for this purpose. The case went to court and remained there for two years. At last in 1917 the Supreme Court of Massachusetts handed down a decision. The money could not be so used.

It was a great disappointment to Professor Thomson and the many educators who had worked so faithfully to give New England a new type of scientific institution. The only tangible result was a long report which the Professor tendered as head of a special committee, outlining his views on the shortcomings of American education. President Lowell wrote to tell him that it was "splendid." Thereafter the two institutions went on their own separate ways, cordial but independent. Legal formality was all that had prevented the combination.

When President Maclaurin died in 1919 Elihu Thomson was asked to take his place at the head of M.I.T. He did not want to

do it; administrational work appealed to him no more now than it had in his younger days. He was still wedded wholly to his home laboratory and his work at the Lynn plant. But the institute persisted, and finally Thomson agreed to become acting president until a permanent incumbent could be found. He held the office for two years, until he was succeeded by his old friend Dr. Stratton. But he was not happy in it; he took little part in the routine of institute affairs beyond the signing of occasional documents.

Nevertheless, his kindly influence continued in the background. A program of tremendous expansion was beginning just then. Much of its later success was founded on his wise counsel.

A similar peacetime expansion of science and engineering was underway meanwhile at General Electric. The electrification of the railroads, of ocean liners and battleships; the spreading of the super-power network throughout industrial America; the beginning of radio broadcasting, television, and short-wave radio communication between continents—these and thousands of other scientific applications were coming over the horizon as the great economic boom developed. The Professor, at his desk in the beehive of the Thomson Laboratory, was at the center of it all. Science, as he had urged, was building a prosperity that would banish war forever.

Yet he himself was slowing down. He was approaching his seventieth birthday, full of honors and experience but burdened with loneliness—a tired, rather wistful man. Donald had become engaged and was seldom at home, Roland had settled in Schenectady; his beloved Stuart lived only as a sheaf of letters which he got out of his desk drawer and read through now and then, dreaming of the torch that might have been handed on. Only Malcolm was still near by, living in a house across the street from the Swampscott estate. There were four grandchildren now.

Professor Thomson all at once felt very old.

But his scientific vigor never slackened, nor his manual skill. He had become greatly interested in color photography and was trying hard to make the postwar Lumière plates do as good work as former ones had done.

Photographic subjects were everywhere. The beautiful New England countryside, that fall of 1922, beckoned to him; the lakes and mountains of former happy days invited him to return.

But it was not yet possible. Traveling, even with his faithful chauffeur, was too lonely. His stout old heart cried out for companionship.

"Well, I have robbed a bank."

So wrote the Professor to Daniel Barringer just before Christmas. He had got himself engaged to Clarissa Hovey, a clerk in a venerable Boston bank. Miss Hovey was many years younger than himself and had been won by a lightning courtship in just four weeks. It was a clear case of love arising from mutual loneliness. The whole affair was so palpably Thomsonian—so swift and efficient, yet so whimsical in its accomplishment—that it deserves a place here. This was how the "unromantic" scientist made love.

The courtship began in October, with the most innocent of scientific inquiries by the Professor. He wrote to her to remind her that he had visited her studio ten years before and had been greatly impressed by some color photography she had exhibited. He remembered that she had been a professional photographer then. He wondered whether she still was. His own interest in the subject had been somewhat thwarted by his very poor success with the recent Lumière plates.

> You had such excellent results, (he said earnestly) that I am prompted to ask whether you have tried any recent plates and with what general result.
>
> Yours very truly,
> Elihu Thomson.

She answered cordially that she was no longer able to indulge the hobby but had often longed to become a "colored photographer" again. Would he tell her more about his own results?

He replied quickly, in detail. He had a projection lantern, a good many slides, and some paintings he had made from them. "Do tell me how we can talk shop; I should be much gratified." Then he spoke wistfully of the auto trips he had once made to capture the colors of the autumn foliage—trips that he longed to make again. He had thought of fitting out a special photographic car, he said, and became suddenly boyish in his enthusiasm for the idea.

He would have three cameras—make the lenses himself (for he was an expert at such work)—travel here and there to find the prettiest spots in the landscape. It was just a suggestion, quickly buried in a description of his family, with special mention of Donald. "He is much more interested in his fiancée than anything else just now," he added.

The Professor wound up with the admission that it was hard to get up enthusiasm for such things as auto trips, now that his wife was gone.

So ended the first week of correspondence.

A few days later he invited Miss Hovey to come and see the slides and meet the family. In due time she came and the occasion was a great success. Shortly arrived a breathless thank-you note. She had been fairly staggered by her reception. He had "shot the works"—Ives process, X-ray burns, Lumière plates, the moon, his jewels, paintings, radio, pipe organ, and grandson. He was interested in so many things, she saw, that he could not possibly get old. And they had been so absorbed—she in the amazing breadth of his talents, he in sharing them with her—that they had completely forgotten the magic lantern and the 10-inch telescope.

Would he come to see her modest array of photographs some day in Boston?

His response to that was to tell her that he had been so inspired by her visit that he had at last taken a really fine autochrome picture. He was encouraged now to go on with his plan for fitting out a camera car "—but it is sorry business doing it alone after all is said and done . . . " Perhaps, he intimated, she would join him on some of those trips he had been thinking about.

Now he broke a lifelong habit and signed his letter "Cordially yours."

That seemed to complete their introduction. He was quickly launched upon the second phase of the campaign.

Soon now they meet at the home of Stuart's widow and enjoy the two grandchildren, Craig and Joan, the latter born after her father's death. And especially they enjoy the little game they are playing. Both know that matrimony is the goal. Elihu Thomson has acquired a new joy in life; his old boyish whimsey peeks out

here and there in letters and conversation. He is calling her "Suite One" in honor of her small Boston apartment. And he is absent-mindedly signing himself "Yours very truly" again.

In fact, he is forgetting right and left. Roland writes to Donald:

> There is something the matter with Father. He signed a letter to me, "Your loving son, Elihu Thomson."

Then comes Thanksgiving, and he has become "Suite II."

Whereupon it is only a matter of working out the details. Nassau or the Riviera—what does it matter where they take their honeymoon?

They were married on the fourth of January, 1923, having all but beaten Donald, who had been engaged for nearly a year.

2

The world had suddenly opened again for Elihu Thomson—a new world of fun and travel—plenty of money, plenty of time, and a charming companion who was as much of a globe-trotter as he himself. They did not delay; February found them in the West Indies, April in London and Paris. Then back home to start on a round of lectures.

His seventieth birthday slipped by without regret, signalized by a dinner with a few intimate friends. He was too happy now to be borne down by the signs of fleeting time—the death of Roentgen in poverty in February, of Steinmetz in prosperity in October, of Mendenhall neither rich nor poor the following summer. He was lecturing with spirit again, filling post after post on committees, skipping about the country, enjoying and enjoyed by everybody. Even the tragic death of Brashear's lens grinder, James McDowell, did not long cast the Professor down, though it saddened all the astronomical world. For years McDowell had had to drink to keep his sanity through the endless hours of grinding and polishing, grinding and polishing on glass. He had become frightened of drink itself, and put cyanide in it. . . .

For Elihu Thomson 1923 was a banner year; it ended even more gloriously. In December the Royal Society of Great Britain notified him that he had been awarded the Kelvin medal. He was invited to come to London the following July to accept it on the

occasion of the Kelvin Centenary. He was the first American ever to receive this, the greatest scientific honor within the power of the English to give.

The spring of 1924 was a fury of preparation. Invitations to speak at various functions in London poured in. He was asked to give the annual James Forrest Lecture before the Institution of Civil Engineers. His desk was cluttered with letters and telegrams from his friends, congratulating him on the coming honor.

The Keystone View Company, learning of his existence for the first time, demanded his photograph. Fame and attention seemed to burst upon him and his bride from every direction. The University of Pennsylvania called him to Philadelphia in February to receive the degree of LL.D.; Pupin came to Lynn to consult him; A. Lawrence Lowell put him on another committee at Harvard; F. B. Jewett of the Bell Telephone Laboratories wrote asking if he might arrange a farewell dinner as the Professor and his wife left for Europe. And in the meanwhile he kept up a cross fire of letters and articles and communications to the technical journals. He had suddenly emerged into a new activity; historian and arbiter to the scientific world.

If the Thomsons had hoped to conduct themselves in London quietly, as befitted a man of ripe years, they were mistaken. Instantly on their arrival they were caught up in the whirl of social activity, the equal of which neither of them had ever experienced before. It was a fortnight-long battle of luncheons, teas, state dinners, receptions, *conversaziones*, and visits to universities, museums, and power plants, done in a style that only the English could contrive. Every function bristled with royalty, the peerage, and the scientific elite of two hemispheres. Every occasion, however slight, was embellished with engraved invitations and menus measured by the pound. Toasts to the royal family, to Kelvin, the Americans, science, were proposed and responded to again and again. The breath-taking earnestness and grandeur of it all so numbed the Thomsons that they did not realize how exhausting it all was.

Professor Thomson was the titular head of the visiting American delegation, which included Kennelly, Millikan, Fred Low, Ambrose Swasey, and many more. From their own roster the British offered Sir J. J. Thomson, Lord Glazebrook, Sir Charles

Morgan, Sir Ernest Rutherford, the Prince of Wales, and the King and Queen themselves. Thomson took a suite at the Savoy Hotel, thinking to be comfortable, but spent so little time in it that its grandeur did him little good.

In thirteen days he and his wife attended twenty functions and he spoke twelve times—just about all he could stand. But these good people had no mercy. As soon as his address was known a flood of invitations to all sorts of private teas and dinners, week ends and visits, descended upon him. Publications and societies asked for his picture until the supply he had brought with him ran out. Mrs. Thomson had planned to save the Professor by a judicious weeding out of invitations; it was hopeless. Every one of them was important.

The jamboree led off on July 3 with the grand banquet of the First World Power Conference of thirty-three nations, at which the Professor was thankful to be only a spectator. But next day he had to "run up" to Manchester to receive a doctor's degree and make a speech in response. Back in London again he and Mrs. Thomson retired to their room to discuss how they ought to behave at the Royal Garden Party at Buckingham Palace next day. Their invitation from the Lord Chamberlain gave no information at all on the proper decorum.

When the time came the palace grounds were a sea of beautiful summer costumes and rigid formality. The Professor piloted his wife to one side. "We'll just stand here," he told her, "and see how Lord Derby's party greets the King and Queen. Then we won't make any foolish mistakes ourselves."

But all at once it was announced that the delegation of scientists was to start the ceremony. The Thomsons, having no time to find out what to do, hurried to the head of the procession, for it was their duty to lead the way.

"Never mind," whispered Clarissa, "just let's act as if we were at home!"

Up they went and shook hands in good old American style with George V and Queen Mary and Queen Mother Alexandria. What a far cry it was for the son of the mill mechanic who had left Manchester sixty-six years before! But the incident went off perfectly.

Scarcely had they recovered from this when the day came for

the James Forrest lecture before the assembled engineering societies. The Professor was at his best facing this celebrated audience, still chuckling over the card he had received that morning announcing that Professor Elihu Thomson would deliver the James Forrest lecture and requesting that Mr. E. Thomson be present to listen.

He spoke on his favorite subject—"Electrical Progress and Its Unsolved Problems"—covering the whole vast field of light and power and communication with his habitual clarity and force. His modesty was as charming as ever; he delighted everyone by giving credit by name to every man whose work he touched upon, and especially to his good friend Colonel Crompton, sitting before him. When the talk was done Crompton responded:

"In his lecture Professor Thomson has referred to my own James Forrest lecture of 1905; I feel it is only fair to say that much that was good and original in that lecture was inspired by him. Anyone who had, as I have, discussed and corresponded with him, must realize Professor Thomson's extraordinary power of drawing out the best in one's nature and of encouraging one to use it for the good of others."

A vote of thanks to the Professor was then carried by acclamation.

He rose again, smiling benevolently. "When a man does what he cannot help doing," he said, "there is not much for which he should be thanked."

A few days later came the presentation of the Kelvin award at the rooms of the Institution of Civil Engineers in Westminster. Sir Charles Morgan gave the honor, and Sir J. J. Thomson and Lord Glazebrook made the speeches. The Professor simply listened.

It was the end of a furious week of activity but not the end of the Professor's obligation to his English hosts. For six more days he had to keep up the pace, rushing from luncheon to tea to banquet—speaking over the radio for the British Broadcasting Company, responding to a toast here, giving an impromptu talk there. His room at the Savoy was littered with programs and menus on which he had scribbled notes of what he wanted to say. He was overcome with kindness, his heart sang with the echo of many praises, but he—and Clarissa too—were fast wearing out.

At last one afternoon they returned to their hotel, weary and bewildered. As she was adjusting his dress tie for the inevitable banquet she said, "You *are* tired, aren't you, dear?"

"I haven't been so tired in years," he sighed and longed to crawl into bed.

Clarissa consulted their engagement calendar. The evening was a blank.

"We have nothing for tonight?" he demanded. "That's impossible. At the meeting this morning they all kept saying, 'We'll see you tonight.'"

"I can't help it," said his wife. "We haven't been invited to a thing. Elihu, aren't you *thankful?*"

Any other kind of man would have been very thankful. But Elihu Thomson could not leave such a thing to chance. He insisted they take a taxi to the Royal Society building just to make sure. The place was dark. Vastly relieved, the Thomsons went back to the hotel and went to bed.

But the Professor couldn't sleep. Presently he got up and dressed all over again—formal clothes and all.

"I am perfectly certain we are expected somewhere," he said. "We've got to find out where."

So they took another taxi and went to the rooms of the civil engineers. These were dark also. Then they tried every other meeting place they could think of, with the same result. The Kelvin Centennial seemed to have disappeared completely.

Feeling very virtuous indeed, the Thomson went home to bed and caught a decent night's sleep. Next day on the train en route to a celebration at Cambridge they met Kennelly. The Harvard professor had a twinkle in his eye.

"What's the matter?" Thomson demanded. "Did we—did we miss something?"

"Oh, just the dinner of the Royal Society given in your honor," said Kennelly.

Thomson was overcome, but Kennelly patted his hand. "I'll fix it," he said. "You forget all about it."

They never found out what the mix-up was or why they had failed to get their engraved invitations as they should.

For the imperturbable English never said a word.

3

The Thomsons went home covered with glory, taking with them the affection of the whole scientific world. If he had wished, the Professor could have gone on to Prague to a meeting of engineers and then rounded off with a visit to Canada for a similar purpose. The invitations were urgent. But he declined them. All he wanted now was home and peace.

Home was indeed a place to be grateful for, that fall of 1924. Its big rooms, its laboratory, its radio; the telescope, the color photography, Malcolm, and the grandchildren. And especially Boston, so near by.

The Professor loved Boston and went there constantly. There were three groups in the city that he delighted to join for discussion: The Thursday Evening Club, the Commercial Club, and the Round Table of the American Academy of Arts and Sciences. At these friendly gatherings he met the most prominent men of Boston—the professional and business leaders who had made the city famous. The Round Table was typical. It included such men as Professors Pickering and Cross, Harold Ernst, Theodore Lyman, George F. Swain, Dr. Wolbach, Dr. Harvey Cushing.

Thomson was a unique spirit among them—the one man who could talk intelligently with each expert on his own ground.

"I can't help but believe," said Dr. Wolbach, "that had he chosen any branch of biology, including medicine, he would have become equally distinguished. All material phenomena seemed perfectly clear to him because he had command of physics, chemistry, and mathematics."

He was like Professor Sabine, who once mystified a banker and an art dealer on shipboard. The dealer was overheard to say, "Judging from his consummate knowledge of painting and painters I think Sabine must be an art dealer, probably on his way to Europe to buy pictures."

"No," objected the banker, "he has too good a grasp of economics for that. I believe he is a financier."

Just then Sabine's small daughter came by; they stopped her and asked what her father really was.

"My papa is a *teacher*," the child told them proudly.

So was Thomson—a teacher to all in their several specialties.

In these years he was busy, happy, and serene. He was now entirely a consultant to General Electric; his office hours were only those that he chose. John McManus knew just how to protect him from unnecessary routine. His wife tended to his correspondence when he let her and managed the details of his financial affairs. She kept the house filled with enjoyable people when he wanted company or bolted and barred it to the outside world when he didn't. He came and went as the spirit moved him. It was in this serene autumn period of his life that he wrote so many articles reminiscent of the early days of the electrical art, while at the same time keeping abreast of the latest advances and continuing his output of useful patents. In the scientific field, astronomy, especially researches in fused quartz, occupied much of his time.

But death would not let him alone; it was his sad duty to contribute the obituaries for his colleague at M.I.T., Professor Cross, and for Charles A. Coffin, who "invented methods of business, displaying originality and imagination usually attributed to artists, inventors and great engineers." He could no longer open his mail without the fear that some dear friend or associate had passed on.

At seventy-two the Professor himself was as energetic as ever. His splendid physique and, as he claimed, the absence of the habits of smoking or drinking, kept him hale and hearty. He traveled about incessantly, delighting his audiences wherever he went.

He still loved Philadelphia and visited it upon every excuse. As a member of the American Philosophical Society, he was there a good deal, never missing a meeting from one year to the next.

Early in 1925 another great honor was bestowed upon him—the Franklin Medal of the Franklin Institute, which he received simultaneously with Professor Pieter Zeeman of the University of Amsterdam.

The affair was a high point in the science of physics, for Zeeman had just announced his discovery of the effect of the magnetic field upon light. It was the final building block in Hale's theory of sunspots—an advance of primary importance to astronomy and the theory of the atom.

There was a wistful note here also. When Faraday discovered

Professor Thomson and F. W. Rice, 1932

electromagnetic induction in 1831 he went on to investigate the effect of magnetism upon every possible substance. His special desire was to show that the magnetic field influenced light as well as matter; this belief he pursued for thirty-five years, exerting every art at his command without positive result. The last entry in Faraday's notebook just before he died suggested a new line of experiment he hoped might succeed. But it was Zeeman who finally did succeed, half a century later, using instruments and techniques beyond the reach of Faraday's fondest dreams. It was the wave length of light and not its direction which could be altered by the magnetic field.

The Franklin medal came to Professor Thomson on much more general grounds. The presentation was made by Dr. Wilbur Rice, "in recognition of his pioneer work in the field of electricity and electrical engineering and of his numerous inventions in these fields." Thomson's interest now, however, was with astronomy; his acceptance address dealt with fused quartz, so soon to make world news in the saga of the 200-inch telescope.

It seemed as if the Professor was destined to go on indefinitely as the dean of American science. But the pace he had led for so many years suddenly took its toll in 1926; in the summer he fell gravely ill of a combination of asthma and gout. For nearly three months he was close to death in Swampscott—the house filled with nurses, his wife scarcely daring to leave his side. Then as suddenly as he had collapsed, he began to get well. Propped up in bed he scratched off letters to his friends, wrote articles, planned speeches, or "excavated for gout crystals" and wrote letters about them to his doctor. It was in this period of his confinement that he made his vigorous protest against the pirating of his helium idea and penned a handsome tribute to Edison for his eightieth birthday celebration. When he had nothing else to do he composed round-robin letters to his numerous family, full of drawings and jokes. One of the strongest forces that supported him was the whimsical letters of Dr. Whitney. The head of the great industrial laboratory had played hooky from his duties and gone out west, digging for Indian arrowheads in Yellowstone Park.

"Perhaps the greatest value of a hobby," Whitney observed, "is the kick one gets out of doing a thing by himself, no matter

how foolish and trivial it may be. I guess an arrow looks attractive to me because it is mine."

That reflected the Professor's own spirit exactly. In spite of all his doctor's fears, he was on his feet again by winter and by spring was ready to indulge in his old delight of chasing eclipses of the sun. In June he and Mrs. Thomson went all the way to Norway for the treat. They were disappointed, for a tiny cloud obscured the sun at the moment of totality. The heavens did not fail them entirely however; the Professor and a few hardy souls witnessed an eclipse of the moon on shipboard at four-thirty in the morning.

On the way home the Thomsons stopped off in London for one more honor—the Faraday medal of the Royal Society. There was no ovation this time, and the aging scientist was very glad.

Chapter 28

I

On his seventy-fifth birthday in March, 1928, Elihu Thomson was a happy man. He was reasonably well; his house was filled with a "happy reunion of sons, daughters and grandchildren—the first we have ever had." During that day and for weeks thereafter the postman came burdened with letters of congratulation.

Dr. Whitney chirped, "I want to celebrate your seventy-fifth birthday, for I can't take chances on being here on your hundredth. But I hope both will be pleasant for you."

Harlow Shapley said, "If you were to measure your life in Martian years you would be three hundred and eleven years old today!"

"Heartiest congratulations," wired Rohrer, "on the completion of your seventy-fifth journey around the sun."

There were letters and telegrams from hundreds of well-wishers in America and abroad. Calvin Coolidge delivered himself of felicitations of unaccustomed length. With his characteristic exactness he wrote:

> My dear Professor Thomson:
>
> I am glad to join with your many friends in extending my good wishes and congratulations on your seventy-fifth birthday. Yours has been a fine record of achievement in many lines. I trust that there are before you many years of useful service.
>
> Very truly yours,
> Calvin Coolidge.

Pupin, Rice, Carty, Sprague, Webster, Stone, Hale, Edison—all added their good words to the President's.

Thomson, however, was no patriarch shuffling about with cane and slippers. He was still very much alive, very much a part of the scientific world. He had just been appointed to the permanent World Congress of Engineers by Herbert Hoover; he was sup-

porting a movement for simplifying the calendar; he was writing his reminiscences, arguing with Harvey W. Wiley about dynamo history, and corresponding with Sir Charles Parsons about optical glass.

Nor was the astronomical note in many of the congratulations a note of farewell. The Professor's years of faithful experiment on fused quartz had at last borne fruit. Just before his birthday he had received a letter from George Hale asking him to come to New York to discuss a quartz mirror for the 200-inch telescope. He couldn't go but sent his assistant, A. L. Ellis, with all the facts.

The plan for the giant observatory on Mount Palomar in California had been forming in Hale's mind for ten years. Ever since the 100-inch Hooker telescope had gone into service on Mount Wilson in 1918 it had been evident that explorations in the outer universe would require a larger instrument still. Hale's first plan was to build a 300-inch telescope, but practical difficulties put that out of the question. It was not even certain that a 200-inch glass mirror could be made and mounted with the perfect precision required for exact observations.

Hale and his associates had considered all possible materials for the great mirror and had agreed that fuzed quartz was the ideal thing—if so gigantic an object as a 40-ton disk of it could be cast. The material would have so small a coefficient of expansion that it would be free from distortion under wide variations of temperature—an advantage which ordinary glass would not have. But could it be made?

Ellis listened incredulously to the plan and hurried home to consult with Professor Thomson. The Professor smiled. "I will make their mirror," he said.

Negotiations were started at once. Dr. Hale and others came to Lynn to thrash out every angle of the matter with the Professor. It was agreed that the Thomson Laboratory would undertake to make several small mirrors—and the big one—at cost.

The Professor, at seventy-five, was young again. He had one of the largest jobs in all science to do. His persistent gout was almost forgotten.

He called in Ellis and they laid out a campaign. Before attempting any disks at all it would be necessary to develop special

machinery and new techniques. Fused quartz was one of the most stubborn materials known to science. The enormous temperature of 3000 degrees Fahrenheit was required to melt it; even then it was sluggish and extremely hard to manipulate.

In his past work Thomson had cast it in slabs after melting in an electric furnace. It should be possible now to turn out a disk of any reasonable size, simply by pouring the material into proper moulds. But it would not be suitable for astronomical purposes in this crude form. The top or mirror surface must be absolutely smooth and homogeneous so that the optical curves could be ground and polished into it to within the two-millionths of an inch of accuracy which Dr. Hale required. Cast quartz was full of air bubbles; even though the heating was done in a vacuum furnace to eliminate many of the bubbles, the surface still would not be good enough.

This was the first problem; to coat the top of the quartz castings with a layer of absolutely clear, bubble-free material. It proved to be a very tough problem indeed.

No matter how hard they tried, Ellis and his technicians could not melt a clear layer onto their trial slabs of quartz. Refinement after refinement was tried with no success. Then at last an engineer named Niedergesass offered a solution. Let the melted quartz be *sprayed* on like water from a nozzle, building up a clear layer by slow degrees.

The Professor adopted the suggestion at once. It seemed the only way.

For the next two years the Thomson Laboratory struggled with technical difficulties that seemed insurmountable, yet moved slowly ahead. "Fused quartz," the Professor had said, "is nothing but sand and energy." The trouble came in supplying that energy in heating and melting huge quantities of sand and keeping them melted till they were safely deposited on the disk surface.

A special blowtorch was invented to provide the hottest known flame, of hydrogen and oxygen; insulated ovens were built; great piles of quartz sand moved into the plant. A 20-inch disk was cast and successfully coated. Work was begun on a mirror blank 5 feet in diameter. Courage and resourcefulness promised eventual victory.

The story of the trial and failure to construct the 200-inch

mirror of quartz is a sad one, yet magnificent, and is told elsewhere in greater detail than is needed here.* The failure was not the result of any breakdown in method, nor did Professor Thomson prove incapable of solving the problems that came up. It was not science but economics that brought final defeat. When six hundred thousand dollars had been spent, and two 60-inch disks had been spoiled, Dr. Hale was forced to call a halt. The sheer cost of supplying the heat to make the disk surface had become too great.

For a time Professor Thomson fought valiantly to continue the work. But Hale was his friend; he could not ask him to spend money indefinitely. For some time he and Hale had been discussing "Pyrex" glass as a possible substitute for quartz. Reluctantly he agreed that it was time to shift the experiments to the Corning Glass Works and begin again.

The last chapter of the quartz saga I have related elsewhere as follows:

> For Elihu Thomson it was the wreck of a voyage of discovery, halfway to the goal. . . . He took it as only a great pioneer can—with courage and silence. No one was to blame. The effort and money had not been wasted. Though the 200-inch quartz mirror was a vanishing mirage, the Professor knew that he had broken the back of the problem in a dozen places, devising techniques which were destined to make fused silica of fundamental importance to science, industry, and medicine.
>
> A little while after that two Corning men went to Lynn to select some of the furnace equipment which belonged to the astronomers. They waited upon Thomson in the outer room of his office; it was the most uncomfortable thing either of them had ever done. When they were at last shown in, the Professor sat at his desk with his head bent down, writing. For a full minute he paid them no attention at all, and they feared the worst.
>
> Then he looked up. In his steady gray eyes there was not a trace of the tragedy of defeat they had expected to see.
>
> "Gentlemen," said Elihu Thomson softly, "I am humbly sorry to have kept you waiting. Please tell me what I can do to help you make the 200-inch Pyrex disk a success."

* *The Glass Giant of Palomar*, by David O. Woodbury.

2

During the years that the attempt had been going on, Professor Thomson had lectured and written enthusiastically about the project. He utterly believed in it; yet over and over again he had explained that success at any given time could not be guaranteed. But the public, even the main body of American engineers and scientists, would not allow the suggestion of failure to stand. The gigantic Palomar project had caught the popular imagination. The quartz mirror must succeed.

Late in 1929 the Professor spoke on the subject, "Why the 200-inch Telescope," before the American Philosophical Society in Philadelphia. The address was carried by a local radio station and reached many thousands of people. The result was a flood of congratulations for Thomson and a mighty boost for the quartz mirror. By January the society had received clippings of two hundred and thirty-six news stories and twenty-nine editorials on his speech.

In that speech Thomson had underestimated the difficulties that lay ahead. But it was too late; publicity men everywhere seized upon the drama of the story and pushed it to the limit, treating the quartz mirror as a certainty, giving too rosy a picture of the whole affair. It was a typical example of overstatement, unauthorized and premature.

Dr. Anderson of the Observatory Council wrote to Thomson deploring the uses of publicity. His letter found the Professor on the warpath, demanding the recall of articles and statements already on the A.P. wires. He was furious for almost the only time in his life. His privacy had been invaded; statements were attributed to him which he did not make; he had been made responsible for claims that were not justified.

From E. W. Rice down, the company officials tried to smooth things out as well as they could. It was a hard job, for the country had seized upon a new hero, a scientist for a change, and meant to make the most of him. Then all at once the whole matter was swept down into the vortex of the stock market crash.

But the Professor never forgave the publicity men. As the hope of success for quartz grew fainter he pointed out angrily that the efforts to make him a celebrity had only succeeded in making him

ridiculous. When failure finally came the brave boasts were hastily withdrawn; the scribes shut up like clams. There was resentment all round.

Then, just to cap the climax, the *American Magazine* published a breezy biographical article about Thomson under the title, "The Bobby Jones of Science." Within a week of publication the Professor had received hundreds of letters asking for money, jobs, favors of all kinds. The proof of publicity's iniquity was complete.

It was characteristic of Elihu Thomson to dislike the press, though it had done him many a good turn. To him, as to most scientists, reporting was all right or all wrong, depending on whether or not it stuck to fact. He did not fully appreciate the element of showmanship always necessary in dealing with the public, nor did he realize that a solid fact may tell an unmitigated lie if it is unintelligible to the man who reads it. In his partial misunderstanding of the connecting link between science and the public lay the reason for his extreme reticence—and for his lack of popular acclaim.

Yet his mistrust was sound; it was only an outgrowth of his deep hatred for all extravagance and sham. Charlatans of whatever kind drew his ire. Unlike most scientists, he went into the lists and fought them, using press and lecture platform to expose all things he found to be false. If no other method served he would sit down and write the offender a long letter, as he did to a man in Ohio who had published a pamphlet on lightning and got it all wrong.

Sometimes he was tartly humorous in disposing of a foolish notion. But mostly he attacked pseudo science with all the deadly earnestness of a crusader. Especially was he militant against spiritualism. His studies in sleight of hand had taught him that even the most intelligent people could be duped regularly by a clever performer. To his mind all spiritualist mediums were magicians taking advantage of the public.

His experience with them had begun early, in Philadelphia. The leading psychic of that day was John W. Keely, who exhibited a mysterious "motor" supposed to be operated by spirit forces. The Professor and his friend Greene attended all the Keely demonstrations, listened to the preposterous jargon of "generators, multiplicators, reservoirs of force, etc.," and denounced it all as a

fraud. They showed that Keely did his tricks with compressed air. Nobody listened to them, however. Keely went on fooling people till 1899, when he was finally exposed. By that time Thomson was contenting himself by drawing hoofs and horns on a picture of the "Great Mystifier" and sending it to his friends.

He and Greene made an honest effort in the early days to give the spiritualist mediums a fair trial—and were thrown out of every séance room in Philadelphia for their pains. It was a lonely road, they found, full of misunderstanding and bad feeling. The public wanted to believe; therefore, the scientists, not the mediums, must be wrong.

Many a great man, before and since, has put his neck into this noose and lost thereby, being hung for a fool whichever way he turned. Faraday made a careful investigation of three mediums in 1850 and thoroughly exposed them all by means of mechanisms slipped unnoticed into their séance rooms. But the article which he published on his findings brought on a bitter controversy, during which Elizabeth Barrett Browning publicly denounced Faraday for his "shallow materialism."

Kelvin was damned for an unbeliever when he characterized animal magnetism as "a tissue of superstition fostered by imposture." On the other hand, poor Sir Oliver Lodge, once a great name in wireless, found himself cordially hated by his scientific friends when he went soft on spiritualism toward the end of his otherwise distinguished career.

There seemed to be no position possible that did not draw fire from one camp or the other.

As he grew older Professor Thomson learned to leave the subject strictly alone. It was safer, he found, to express no opinion at all, since anything he said was bound to be used against him. Thus, when his own company became a party to a psychic fraud he "kept still and sawed wood."

There was a vaudeville team at one time known as "The Fays," who toured the circuits doing a spiritualist act which was very convincing. For their furniture they used a trick table full of concealed wiring that gave the necessary sound and lighting effects to simulate the spirits.

Thomson didn't know it, but that table had been built at the Lynn works of the General Electric Company. That is, he did not

know it until his son Stuart came in one day with a telegram he had found in another office. The telegram was a desperate appeal from the Fays, who were on tour. Send a new table quick, they said. Their old one had broken down.

At the height of the Professor's popularity in the Boston scientific meetings the great medium Margery Crandon was absorbing the attention of investigators all the way up the scale from Houdini to Harlow Shapley. To look into Margery's case Professor McDougal of the department of psychology at Harvard and many others of the highest repute started the Boston Society for Psychical Research, and Thomson was persuaded to join. But he lent his name only, not his presence.

When this group began its study of Margery, the Professor declined to sit with them. He told them that he had been through it all long ago, and that Margery would make fools of them all. "You are sure to become besmirched in the end," he warned them, "especially if you succeed in discrediting her."

"As we did not heed his advice," wrote Dr. Wolbach, who was of the party, "his prediction was verified; we were thoroughly blackguarded in print by her at a time when she was still in vogue."

McDougal is reported to have said, after an impressive séance with Margery, that if he had really seen what he thought he saw, a whole lifetime of teaching would have to go by the board. Professor Thomson had shown his wisdom in keeping clear of the affair, for even today there is a large section of opinion which holds that this medium was genuine. Fortunately for him, perhaps, he died before science was obliged to face the probability that there *is* something besides fraud to be explained in psychics after all.

Fortunate, too, to have died before a reporter on the *Philadelphia Record* tripped and stumbled through an account of Thomson's early welding discovery in that city, spelling the Professor's name wrong and otherwise mauling the simple truth:

"Dr. Thompson," spouted this young man, "was lecturing on electricity at the Franklin Institute. Somehow his wires got jammed; there was a burst of current, and the wires melted a little and stuck together. Dr. Thompson cussed professorily, then went back to his laboratory to find out why it happened."

How "professorily" he would have cussed had he read this effu-

sion and been forced to do nothing while it circulated through his beloved Philadelphia!

3

Although the 200-inch quartz disk held the attention of the whole Thomson Laboratory the Professor himself did not spend all his time on it. He had reached the point where he could not concentrate exclusively on any one thing. If anything, his interests were more diversified than ever. Thus at the height of the work on quartz he suddenly proposed a method of mosquito elimination.

It was a delightful example of his ability to go from cause to effect. Ellis had noticed that the electric resistance furnace for heating the quartz disks attracted and killed an amazing number of mosquitoes one summer. He couldn't understand it. But Thomson solved the riddle at once. The furnace hummed with the 60-cycle current flowing through it. Undoubtedly the insects were males that had been misled by the similarity of the sound to the female's mating call. He collected some of the corpses and tried to determine their sex. This failed. Then he took the question up with his friend Professor Parker of the Harvard department of zoology. Parker told him that his corpses were indeed males.

This suggested a way to get rid of mosquitoes by the thousand. If the males could be lured to their death by electricity, no more eggs would be hatched by their intended mates. Thomson sent a communication to *Science* about it. "It is easy to organize an electromagnetic 'hummer,' " he wrote, "which can spread over a large space the peculiar hum and attract the males. Can the whole race of them be thus decimated or extinguished by proper utilization of these principles?"

General Electric's mounting troubles with quartz prevented them from going into the mosquito-extermination business. But there was the idea—a gem ready to be picked up by anybody who might wish.

Travel soon lured the Thomsons again. They fairly became globe-trotters in the next few years. Africa, Arizona, Bermuda, the West Indies and South America, the Canadian Rockies; one after another they visited them—all the places that they had dreamed of and longed to see most. Thomson was an excellent

traveler. He never got seasick (except once crossing the North Sea, which he insisted was from eating goat cheese). And he had no end of fun pacing about the ship incognito or holing into some corner for a long discussion with a casual acquaintance. Once Mrs. Thomson lost him completely just at dinnertime and was beside herself for fear he had "fallen overboard without thinking." After that she made a rule that he was to report in their cabin half an hour before every meal.

He did. Promptness became such a virtue with him that when they were landing at one Mediterranean port the Professor had their baggage at the gangway hours ahead, so as to be the first ashore. The plan worked splendidly. But the trunks wound up at the bottom of a huge pile on the dock and the Thomsons were the last to leave.

In 1931 they made their final appearance in England, mellow now and full of honors. The Professor had been asked to participate in the centennial celebration of Faraday's discovery of electromagnetic induction. He got no medals this time because he had received all there were to give. He made almost as many speeches as he had in 1924, the most important being a lecture before the British Association recalling his early work on dynamos and lights.

He was beginning now to live in his past.

When he could, he sat back and listened, saying a few words here and there, basking in the affection that shone upon him from every side. He enjoyed the role of spectator gazing benevolently upon a younger world. Once he and his wife came late to a lecture by Sir William Bragg, slipping in through a side door and taking seats at the back of the hall. They hoped they would pass unnoticed.

But it was not to be. Sir William had seen them come in. At once he broke off his discourse and said to his audience:

"You will be happy to know that Professor and Mrs. Thomson have just entered. Let us greet them."

Without a word everyone in the hall stood up and applauded.

I

Chapter 29

The year 1932 found Elihu Thomson approaching his eightieth birthday with the reservoir of his mental energy still generously filled. He was spending most of his time at home now, writing reminiscences, playing his organ, going "across the bridge" to his laboratory for several hours a day. On one of these occasions Mrs. Thomson suddenly realized that her husband had donned old clothes and had been missing for a long time. Usually he was seen or heard every few minutes; this time there was no trace of him. She had a moment of panic; had the Professor fallen into the open cistern behind the house?

Family, maids, and chauffeur spread out over the estate in a hurried search. Malcolm telephoned that he had "seen Father cross over the bridge." But he was not in his shop. . . .

Finally the Professor was discovered in the carriage-house cellar, in the half darkness, sitting on the cylinder of his big air compressor, utterly immersed in taking apart a valve. He was covered with grease and grime and was whistling to himself softly —an artist in the midst of his creation. Yet his thoughts were far away.

"I have been thinking," he said, "of Tom Edison, and how extraordinary it is that he has died."

It did not seem possible that so virile a mentality as Edison's could have suddenly ceased to exist, its mighty energies reduced to nothing. Science believed so firmly in the persistence of energy; it could be converted into many forms but never destroyed. Yet— science gave no hope of life after death. It was a paradox.

Elihu Thomson was beginning to feel the chill climate of old age, when the warmths of many friendships were snuffed out one by one. He was speculating more and more now—gathering up his philosophies, looking back upon the world he had helped to create, setting it up in the ledger of profit and loss. What had been his contribution? What did it mean for the future of mankind?

His works might possibly survive, he thought, but he himself would not. Death was close now, and it meant annihilation. He could not bring himself to believe in a hereafter. He did not want to believe in one.

While his hands were still rich with the indelible stains of a lifetime of experiments, his thoughts soared, touching the mountain peaks of contemplation. Death was an end, not a change, as the church taught. When one's work was done, one simply ceased to be, like a chemical reaction completed.

He had lately summed it up well, he thought, in a letter to "Cornelia"—carefully framed but never sent because he knew that she would not understand. He was discussing the survival of her departed mother's spirit after death, and the uselessness of theorizing upon it.

> We cannot believe even if we should wish to, unless our reason assents to the truth of any proposition. In fact, an honest person would never wish to believe if reason denied the possibility. I have read extensively on many subjects and studied more. In the current religions (all of them) there are contradictions and inconsistencies. I cannot accept any miracle except the one great miracle of the Universe itself, infinite in time in both directions.
>
> God will know whether we little humans should live forever or not. The thought itself is appalling—not billions of years, but billions of billions and on. Why should we want that? It seems to me to be a more fearsome thing than ceasing to live. Why not leave it all to God? . . . Whatever God has for us I know will be right, and I am sure He will not be more cruel than I would be to my sons.

Among the Professor's papers was a letter from Edison to Joseph Lewis on his book, *The Tyranny of God*. Edison had said:

> I think as you do that death ends all, yet I do not feel certain, because there are many facts that seem to show that the real units of life are not the animal mechanism itself but groups of millions of small entities living in the visible cells—the animal being their mechanism for navigating their environment. And when the mechanism fails to function, *i.e.*, dies, the groups go out into space to go through another cycle. The entities are

> each highly organized and perform their allotted tasks. If there is anything like this we still have a fighting chance.

But Thomson could not agree to this; it was too definite—too mechanical. It entered a realm which was beyond the reach of human thought. Such theorizing was useless—it led to nothing—it was like working in a laboratory without apparatus or tools. More strongly than ever he believed what he had written to a correspondent in 1901:

> I can scarcely agree with your idea of completeness and justice coming after, as in the case of Lincoln. The fact that he still lives (figuratively), enshrined in the hearts of men, cannot be a working of justice to him, being dead. His forlorn youth, his cares in life, unless compensated in life, leave injustice still. Lincoln dead becomes an ideal, a moving force for those who survive or follow him. As a *living man* he receives no reward. . . .
>
> In the past man has given so much time and thought and effort to trying to do the impossible, to endeavoring to interpret the signs which do not have any relation to his affairs, to compelling his fellow man to think and believe as he himself did, that he has been a creature of neglected opportunities. He is still, except in some favored regions, engaged in the same criminal neglect of opportunity, actively at work wasting his resources.

In other words, let man mind the business which was set for him by God; let God alone tend to the problem of the hereafter. That was Thomson's considered belief; he held it to the end.

But he was a scientist, not a fatalist. He did what he could to defeat death for himself and others, and when that was not possible, he strove to assuage the pangs of bereavement. His understanding of the meaning of death was well illustrated now in 1932.

Late in December his friend Edward Mallinckrodt came to him in desperate need of help. His son, learning to fly at near-by Nahant, had plunged with a companion into Lynn Harbor and was lost. There was no question of finding him alive. Navy tugs and fishing boats had searched the bay for two weeks without result. Everyone said that it was hopeless—the bodies had sunk with the wreckage and had been carried out to sea beyond recovery.

But the father could not bear the thought of his son's body

drifting like a derelict forever through the Atlantic. Was there not something the Professor could do to find it?

Thomson gave him hope at once. He assured his friend that the currents were not strong enough to carry the plane away.

"Have courage, Edward," he said. "We shall find him for you."

Quickly he got hold of Malcolm and laid out a plan of campaign. He got charts of the harbor and studied the currents; laid out the probable course that the wrecked plane would have taken along the muddy bottom. Then he had Malcolm borrow a rowboat and set out a number of wooden floats to test the current more accurately.

When the data were assembled, Malcolm got a friend at the factory and set out in two boats, dragging a chain back and forth across the bay between them.

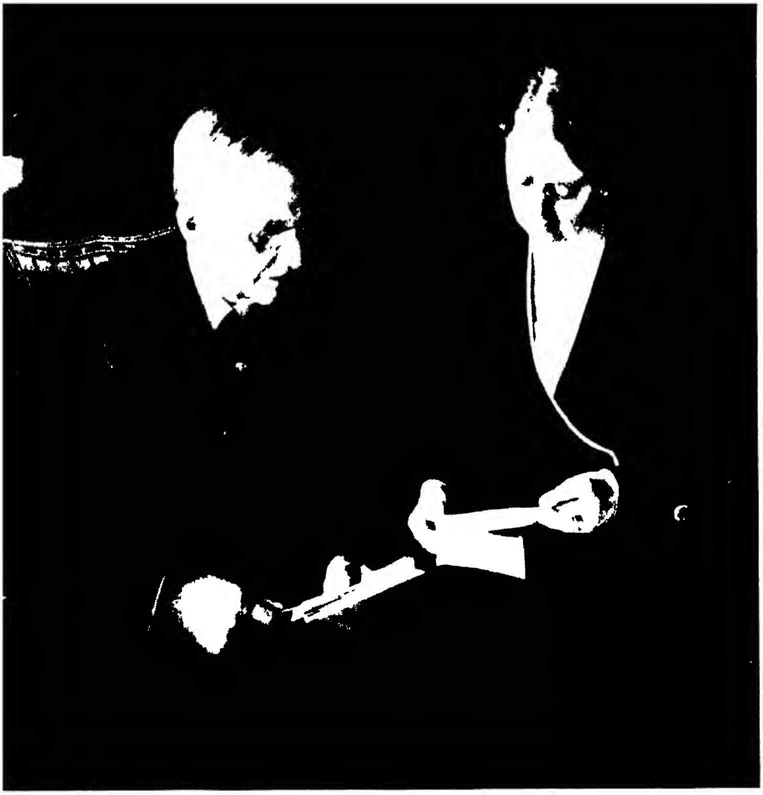
Week after week of search in the icy bay brought no results. Mallinckrodt gave up hope and went back to St. Louis. But Thomson would not give up. Day after day he worked over the charts, laying in the areas that Malcolm had covered, sending him back to renew the search. Though he did not leave the house himself he supplied the courage and the technical knowledge which kept the others going.

At last his faith was rewarded: the plane and both bodies were located and hauled to the surface with the Navy's help. It ended as Thomson knew it would. The father's gratitude was touching. "We laid our son in his final resting place decently and reverently," he wrote. "And this is no small satisfaction." He thanked the Professor from the bottom of his heart for having made that final rite possible.

Thomson's general philosophy of living was simple: to inquire first, then to act accordingly. "Prove all things and hold fast to that which is good" was his favorite motto. He wrote but little on the subject and said less, deeming it better to live his principles than to preach them. His unshakable faith in the rightness of the scientific way survived every attack. The search for new knowledge was his creed; because he thought religion stifled this search he abhorred it.

Once he wrote these heretic lines:

> Religious formulae and observances are often based upon the common advertising idea that if a statement is repeated



Professor and Mrs Thomson read eightieth birthday congratulations

> often enough, especially to the youthful mind, it gets ground in and accepted as truth, notwithstanding its real origin. I have asked the question throughout life, why, if these religious doctrines are true, is it necessary to constantly repeat, repeat and repeat? As if they would be absolutely no good if not continually reiterated. I could never see any reason why, if God has been prayed to for certain things—safety from harm, or for blessings—the same petitions should be continually worked over and over again.

Yet no one who knew this man could doubt that he was a better Christian than most who professed a creed. It took courage to fight through life without the emotional help of religious forms. He knew that there was help there for the weak and weary, yet he could not accept it, for to him religion was not Truth.

His last formal speech—before a meeting of the American Academy of Arts and Sciences—showed the extraordinary elasticity of his mind, yet at the same time demonstrated his love for ferreting out little grains of truth. The paper was called "The Krakatoa Outbreak," and dealt with the explosion, in August, 1883, of that famous volcano in the East Indies—"the worst calamity of the kind in modern times," which was said to have killed nearly forty thousand people.

The disaster occurred when Thomson was just changing from New Britain to Lynn, so that he had no time to study the voluminous reports of the Royal Society which were made on it. But the phenomenon had always interested him: the gigantic tidal waves; the sound that had been heard three thousand miles; the volcanic dust that had traveled around the world and made the "yellow day." Now, half a century later, he had found something new to report on it. Hearing that a Dutchman by the name of Van Gestel was in Lynn and that he claimed to have been the only surviving witness of the eruption, he sent for him and had his secretary take down a verbatim report of the whole affair.

This the aging Professor read to the Academy almost without comment. Van Gestel had been commissioned by the Dutch government in Java to follow the progress of the eruption. He had visited Krakatoa island in Sundra Strait when it had first shown signs of trouble in May and had remained for four months, taking photographs and studying the eruption at the risk of his life.

Thus, by taking advantage of a chance acquaintance, Thomson had been able to add a fragment to the world's knowledge of geology. Of the human terror and misery he had little to say. The most humane of men, he was not one who would drag the red herring of "social significance" across the scientific trail.

2

On the Professor's eclipse expedition of 1932 in New Hampshire, Rohrer drew Mrs. Thomson aside and made a suggestion that had long been in his mind. Why not arrange a great dinner and celebration for Elihu Thomson on his eightieth birthday the following spring? Let it be held in the banquet hall at Massachusetts Tech, representing the tribute from the scientists of both hemispheres.

The idea gained immediate support from all quarters. Professor D. C. Jackson at M.I.T. enthusiastically took the chairmanship of a committee of arrangements and sent out invitations to prominent people everywhere. Thomson, when he heard of it, was inclined to demur modestly. He had shot his bolt, he said, and did not think so much fuss should be made over him. But the scientific world disagreed. The response was universal. Hundreds of letters and telegrams poured in, especially from Europe. Those who could not come sent glowing tributes; the list of acceptances included the most prominent men and women in the engineering fields.

Professor Jackson and President Karl T. Compton were anxious to make the affair more than a dinner. They wanted it to be an official recognition by the institute and by science at large of Thomson's long lifetime of achievement. Thus before the banquet a scientific conference was arranged, together with an exhibition of the Professor's choicest historic relics—the wine-bottle electric machine, the first three-coil dynamo, the earliest arc lamps, the celebrated wattmeter that had won the Paris prize, the "jew's-harp" welding transformer and many more. The guests gathered around, fascinated. Here was the work of a lifetime, every item of which had been built into the fabric of the world's daily life.

If there had been any fear that Professor Thomson was too feeble to perform his part as guest of honor, it was quickly dispelled. Seeing the throng examining his little wine-bottle machine, he seized the crank and proceeded to demonstrate just how he had

thrown his father to the floor sixty-nine years before, commenting all the while with the familiar twinkle in his eye.

The banquet itself was one long ovation, dominated all the way through by the unassuming figure of the Professor. Much of the time as he sat and looked out over the handsome gathering there was a faraway look in his eye; the pageant of a lifetime was passing before him.

Dr. Compton opened the speechmaking. "This is not the time to discuss technical aspects of Professor Thomson's work," he said. "But it is fitting to say that he has contributed more than any man now living to the creation of what we call the 'Age of Electricity.'"

He then read a telegram from the White House:

> The President wishes to testify to Professor Thomson's outstanding contributions to science, the arts, and his distinguished citizenship.

Then followed a brilliant list of speakers, beginning with Governor Ely of Massachusetts, including leaders in science, medicine, and education. The last was Dr. Rice, who spoke from his heart on the simple theme, "My Professor."

Dr. Harvey Cushing, representing the medical fraternity, gave a whimsical touch to the evening by expanding upon the name of Thomson itself. After roaming the world and bringing back Rumford, Kelvin, Sir J. J., Sir Wyville, and half a dozen more of equal distinction, he suggested that Elihu, "Baron of Lynn and Swampscott," was really a composite of them all. If one were to provide him with the initials of all his inventions—A.C., D.C., H.V., W.T., and the rest—he would cover the list of all possible Thomsons.

It was a neatly turned and affectionate compliment, coming from the world's greatest brain surgeon. Dr. Cushing summed up his thought with this:

> But when we actually come to fuse all these Thomsons of our immediate vicinity and to get a composite picture of them, it becomes quite evident that the resultant Elihu is one of those rare men who transcend their own chosen walk in life and who belong to us all. It is not their genius alone which is responsible for this, however rare a gift genius may be. . . . It is only when

genius is combined with those equally precious qualities of modesty, unselfishness, and simplicity—the imponderables of high character and lovable personality—that there emerges from the common herd an occasional man whose life symbolizes something as nearly perfect as one could hope to attain in this fallen world.

When the speeches were done, the Professor thanked them all tenderly, then turned the spotlight from himself to the Massachusetts Institute of Technology and the great work it was destined to accomplish. His own modesty was the greatest eulogy of the evening.

3

Though everyone who spoke at the birthday dinner was eloquent, there still remains no truer evaluation of Professor Thomson's real worth to the world than that made by Owen D. Young in a speech in 1930. He had been discussing the pioneer work that Professor Thomson and his pupil Wilbur Rice, had done in making electric energy "portable, divisible, and sensitively controllable." He had brought in the symbol of the balance sheet, asserting that whatever a man's contributions to the asset side of society's account might be, there was inevitably an entry to be made on the liability side as well. He said:

> A fair appraisal of a man's effort is not what he has written on the asset side of the balance sheet of life, but how much of the counterbalancing entry on the liability side is *surplus*.

The plants of the General Electric Company, said Owen D. Young, were valued at $209,000,000, to which neither Professor Thomson nor Dr. Rice had contributed a penny. The quick assets of the company, a similar sum, were likewise innocent of their help. And the patents of the concern were entered on the balance sheet at one dollar. And yet—

> . . . there is not an item on that sheet which could have existed at all, or if it did exist, would have been worth putting on the asset side of any balance sheet, had it not been for the work of Professor Thomson and Edwin Wilbur Rice. There is not an identifiable separate thing that stands there as their monument—it is the balance sheet itself.

> It says that our assets are $500,000,000. The market says our shares are worth $2,000,000,000. If you wish to subtract the first from the last figure, you will get an evaluation of the intangibles, a substantial part of which was contributed by our guests.

What these intangibles were, in Professor Thomson's case, Owen Young had subsequently explained in an interview.

> Professor Thomson stood behind the scientists of the nation and of the company—a great and mostly silent figure. The very fact that he was there was enough to give them impetus. He had tremendous power at General Electric; the mere fact of his presence was a mighty force in allaying trouble. Few controversies actually reached him—he never knew they existed. They were settled, so to speak, out of court.
>
> If you were greatly troubled on any subject, there was no better way to clarify your mind than to talk to Professor Thomson. All your little irritations, annoyances, and prejudices would disappear in his presence. You threw them out of your mind before you saw him, lest you inadvertently disclose them to him.

He was like a supreme judge, who maintains peace by his authority rather than by his decisions.

"What Elihu Thomson did made him distinguished," concluded Young. "What he was made him great."

Charles A. Coffin liked to tell of a small boy who visited the plant with his father many years ago. Immediately the child asked to be introduced to "General" Electric. Coffin sent for Professor Thomson. "This, my boy," he said, "is 'General' Electric."

Lord Kelvin once put upon the blackboard before a class this formula:

$$\int_{-\infty}^{+\infty} \epsilon^{-x^2}\,dx = \sqrt{\pi}$$

"A mathematician," he explained, "is one to whom that is as obvious as that twice two makes four is to you."

The great formulas of nature herself and of the universe, and of humanity were as obvious to Thomson as that bit of jargon was to the skillful mathematician.

Chapter 30

1

Soon after his eightieth birthday triumph Professor and Mrs. Thomson traveled westward again to the Canadian Rockies, then swung back through the northwest to the Chicago World's Fair. The Professor stood the intense heat—over a hundred—for several days and then, back home again, collapsed. He had come to the end of his superb strength.

For six months he lay close to death in Swampscott, ill of a malady that his doctors could not fully diagnose. Then, slowly, he began to recover. But he had, as he said, "shot his bolt." Never again was he able to participate in the world's scientific affairs. For the next three years he lingered on in Swampscott, sometimes suffering a relapse that brought his family to his bedside, sometimes well enough to ride into the country or to sit at his desk and compose a brief article or write a letter. Gradually the fire of his great spirit dimmed; the mental energy that had helped create a new age seeped away.

In the summer of 1934 he was sufficiently on the mend to preside at a meeting of his beloved Peabody Museum in Salem and to go for a few weeks' mountain air at Peckett's on Sugar Hill in New Hampshire. But shortly he was down again, fighting for life against asthma and its complications.

His eighty-second birthday found him once more recovered. It was a happy occasion, for Rice and Rohrer came out to visit him. Rice brought with him the last of the long series of honors—the German engineers' Grashof Medal, which the Nazi Consul General in Boston had presented to him through Dr. Rice.

What the Professor thought of this tardy recognition he did not say. He had already conceived a deep distrust of the upstart Hitler; in his view the German nation had lost its place in the world of human beings. Even its scientists and engineers were second rate.

The presentation speech of the Nazi official was noncommittal, but the publicity broadcast by the German press in the home country and carefully sent to America in translation was an amazing blend of arrogance and veiled insult. It was just as well that the Professor was too old to appreciate its implications.

The summer passed happily; Professor Thomson took many rides in his car into the woods and to the shore at Salem and Marblehead. Then the clouds gathered around him again. Tragedy and death were striking close now. Professor Kennelly wrote:

> I was laid up for about a year following my cataract operation, from nervous reaction, dyspepsia and insomnia, but I am now approaching concert pitch, I trust—say within an octave of it.

Kennelly's eyes had failed. He was going blind.

George Hale was confined to his house in Pasadena, too ill to carry through the work on the Palomar Observatory. Ritchey was in a sanitarium. On every side the Professor's generation, though still fighting valiantly, was going down to defeat. In that one year thirty-five friends and associates died.

Then in November came the news that Wilbur Rice had gone. For the Professor the old days had surely come to an end.

But he himself stayed on.

Now and then he was well enough to play the organ or to "cross the bridge" for a few minutes to putter in the beautiful disorder of his laboratory. Sometimes his friends came to see him: Dr. Whitney just to sit and say nothing; or Nelson Darling, manager of the Lynn plant, to show the old pioneer the latest things the laboratory had turned out in the way of meters, switches, motors, and all.

The day that Darling came with his chief engineer, bringing a suitcase full of shining new gadgets, was a happy one for Professor Thomson. They spread their display out on his bedroom table and he examined them all with delight, while his guests beamed over his shoulder.

They got him a screw driver, and he took the little machines apart, one by one, his fingers as sure and steady as ever. "Clar-

issa!" he would exclaim at each new discovery, "look how they have done this! We couldn't do it before, for we didn't have the materials. But now we can!"

He was so ill, so weak, yet so tenacious. He wanted so much to live on just to see how the great detective story of electrical engineering "came out."

Then, shortly, there was another birthday—his eighty-third. He had been consistently overdoing in his study; the celebration was too much. Down he went again to fight for his life. That was the beginning of the end. Only with adrenalin and oxygen did he continue to survive, rallying many times against his doctors' word that he could not.

There were good weeks and bad; periods when miraculously he seemed on the road to real recovery, or when he was too near death to recognize its call. His sons and his grandchildren gathered around; the house was filled with nurses; his wife went for days and nights without going to bed.

His room, fixed exactly as he had ordered it, was a laboratory. Cooler, ultraviolet lamp, oxygen tank, sun lamp—balanced by an aquarium of goldfish and a marmoset monkey which he named "Haile Selassie."

As the dying Professor lay there waiting, his family waited also. The big house seemed charged now with his personality. Elihu Thomson the scientific pioneer had gone on ahead into history; Professor Elihu Thomson the teacher, the beloved friend and head of the family, was present everywhere. His kindness, his generosity, his quick interest; his simplicity, his devotion to others—these things were all around, invisible yet increasing every minute.

They all knew what this subtle presence meant; it meant that their own minds were filling with memories; they were unconsciously schooling themselves for the moment when they must look back. They were preparing for life as it must be lived with him only in their hearts.

Memories—

Of your humility: Do you remember the time when Silvanus Thompson, the old British aristocrat, stayed with us and put his shoes outside his door every night to be blacked? And you insisted on blacking them yourself, Elihu? You said Abraham Lincoln

blacked *his* shoes himself, even in the White House, so why shouldn't you do this little service for your friend?

Of your wit: Remember the time you got into an argument with Fred Fish over the theory of evolution? And Fred had you stumped when he demanded to know why primitive man didn't develop an eye in the back of his head to protect him from his enemies? And finally you said, "There's one thing about it, Mr. Fish. If he had had such an eye, he would have got sand in it when he lay down to sleep."

Of your whimsey: Remember the little notebook where you kept a record of all the different ways people had misspelled your name? Faraday did the same thing, you said, but never was he so plagued as you were. (Mr. Ulihu Thomas, Mr. Eliush Thompson, Withu Thomson, Esq., Professor Ether Thomson.) And once you brought home an envelope properly addressed to you at the company, stamped with four different notations: "Not in Test," "Unknown in Turbine Department," "Not employed by Sales Division," and all that. You were not mad; you were just amused.

Of your kindness: That time in a neighbor's garden, when the gardener summoned us with such delight to see the hummingbird you'd told us was so beautiful to watch. Remember? You just stood there and said nothing. Then afterward you said, "That wasn't a hummingbird but a moth. But I didn't want to hurt his feelings by telling him so."

Memories, for the sons and the grandchildren, too.

Of your cleverness, grandfather: *We* remember the times best when, on picnics, you would send us out to gather in bits of stick and wire and tin, and then build dams and real water wheels that turned around. You never took the materials along; you always made out with what was there.

Of your practical joking, grandfather: *We* remember the mirrors you used to draw soap lines upon and then accuse us of having broken! And the "spanker" you said you'd fixed up in the laboratory by putting a leather belt on the shaft of a lathe so it went flap! flap! flap! at a thousand revolutions a minute. "The first one of you that breaks another mirror," you warned, "will be taken to the shop for a trip through the 'spanker.'"

Of your wonderful way of explaining things, grandfather: How you used to throw yourself down full length in the snow and

have us shovel it all in around you and pack it down. And then how you'd get up so carefully and leave a hole just your own shape. We remember that, too. You said that was the way they made castings in the plant—with a pattern. You laughed and said you were a pattern yourself. Remember?

Memories—that crowded in upon them all; and not a memory was sad. His sweetness and understanding and his love of children of all ages had come to stay, in the Swampscott house—everywhere.

The Professor had left his upstairs room at last, to live in the world's heart for always.

His imprint would lie in the snows of scientific knowledge forever.

He was a pattern—the pattern of the search for Truth.

Bibliography

There follows a short list of biographical and other books which give further information on the period in which Elihu Thomson lived and on the lives of the men with whom he was associated or whom he emulated in the various fields of science and engineering.

Benjamin Franklin, by Carl Van Doren, The Viking Press, New York, 1938.

Memoir of Joseph Henry, by William B. Taylor, Government Printing Office, Washington, D.C., 1880.

Michael Faraday, His Life and Work, by Silvanus P. Thompson, Cassell & Co., Ltd., London, 1901.

Life of Lord Kelvin, by Silvanus P. Thompson, Macmillan & Company, Ltd., London, 1910.

James Clerk Maxwell and Modern Physics, by R. T. Glazebrook, Cassell & Co., Ltd., London, 1896.

From Immigrant to Inventor, by Michael Pupin, Charles Scribner's Sons, New York, 1924.

Edison, His Life and Inventions, by Dyer, Martin, and Meadowcroft, rev. ed., Harper & Brothers, New York, 1929.

Wallace Clement Sabine, by William Dana Orcutt, Plimpton Press, 1933.

The Autobiography of John Hayes Hammond, Farrar & Rinehart, Inc., New York, 1935.

A Genius in the Family, by Hiram Percy Maxim, Harper & Brothers, New York, 1936.

Men and Volts, by John W. Hammond, J. B. Lippincott Company, Philadelphia, 1941.

Modern Wonder Workers: A Popular History of American Invention, by Waldemar Kaempffert, Blue Ribbon Books, Inc., New York, 1931.

American Martyrs to Science through the Roentgen Rays, by Percy Brown, Charles C. Thomas, Publisher, Springfield, Ill., 1936.

The Magician's Own Book, Dick & Fitzgerald, New York, 1870.

A complete list of Elihu Thomson's published papers and patents would be far too long for inclusion here. For purposes of reference a good abridged list of both will be found in *Biographical Memoirs of Elihu Thomson*, by Karl T. Compton, National Academy of Sciences, Washington, 1940.

Copies of all Thomson patents are on file at the library of the Franklin Institute, Philadelphia. His collected writings are available for examination at the library of the American Philosophical Society, also in Philadelphia.

Elihu Thomson's Medals and Decorations

1888. The John Scott Legacy Medal and Premium of the Franklin Institute.

1889. Grand Prix from the Paris Exposition.

1889. Chevalier et Officier de la Légion d'honneur.

1893. Gold Medal Certificate from the Columbian Exposition.

1898. Medal of the Trans-Mississippi Exposition.

1900. Grand Prix from the Paris Exposition.

1901. The Rumford Medal of the American Academy of Arts and Sciences.

1901. The John Scott Legacy Medal of the Franklin Institute.

1904. Medal of the Louisiana Purchase Exposition.

1909. The Edison Medal of the American Institute of Electrical Engineers.

1912. The Elliott Cresson Medal of the Franklin Institute.

1916. The John Fritz Medal of the combined Engineering Societies.

1916. The Hughes Medal of the Royal Society of Great Britain.

1924. The Kelvin Medal of the English Engineering Societies.

1924. The Franklin Medal of the Franklin Institute.

1927. The Faraday Medal of the Institution of Electrical Engineers.

1935. The Grashof Medal of the Verein deutscher Ingenieure.

Index

P

R

S

T

U